WARM FOG DISPERSAL METHODS AND FOG CHARACTERISTICS AT MONTEREY, CALIFORNIA.

by

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THESIS

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ABSTRACT

As a prerequisite to a study of fog dispersal, the literature is surveyed and the various methods of warm fog dispersal are summarized. From an analysis of weather observations during June 1968 - May 1969 at the Naval Auxiliary Landing Field, Monterey, California, it is concluded that the early morning hours of September through November present the highest frequency of fog occurrence and would, therefore, be well suited to fog dispersal field tests. A hand-held, gelatin-coated glass slide method of obtaining fog samples is evaluated in the process of determining the fog droplet distribution in fog and stratus occurring on the Monterey Peninsula. It is found that the distribution is centered about a radius size of 10 μ and in good agreement with current fog models. A series of laboratory experiments using various household detergents as seeding agents are discussed.

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C_p	Specific heat of moist air at constant pressure
E	Collection efficiency of falling water drops
e	Saturation vapor pressure over a water surface, general
e_c	Saturation vapor pressure over a curved pure water surface
e_h	Saturation vapor pressure over a plane salt solution surface
e_{hc}	Saturation vapor pressure over a curved salt solution surface
e_s	Saturation vapor pressure over a plane pure water surface
H_a	Heat quantity required to heat a given air parcel
H_w	Heat quantity required to evaporate the liquid water content of a foggy air parcel
L	Latent heat of vaporization
m_a	Mass of air
m_w	Mass of liquid water content
N	Number of particles or droplets
R_v	Gas constant for water vapor
r	Radius of water droplet
$\bar{r}$	Mean linear radius of a droplet sample
$\bar{r}_v$	Mean volume radius of a droplet sample (half the total volume contained in smaller droplets)
T	Temperature
V	Visibility
W	Liquid water content of fog
μ	Micron
ρ_v	Density of water vapor

ρ_w Density of liquid water

σ Surface tension of a water droplet

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I. INTRODUCTION

Although considerable progress has been made in recent years in the field of meteorology, there remain a number of problem areas which challenge the imagination and skill of our most perceptive minds and talented technicians. One such problem area is warm fog.

Fog is classified as either warm fog or supercooled fog, depending upon whether its ambient temperature is above or below 0C. In either case, fog consists of a visible aggregate of minute water droplets suspended in air, saturated or nearly so, and which, according to the international definition, reduces visibility to less than one kilometer (Huschke, 1959). It is the latter restriction which distinguishes fog from haze and mist, progressive forms of the same phenomena involving increasing relative humidity and decreasing visibility.

The problems associated with the insidious nature of fog are major ones. They are of concern to the individual because they are intimately known by him. He is familiar with the hazards of foggy highways and the inconvenience of delays in air travel. At the other end of the scale are the institutions to which fog is not simply another problem but an urgent one that interrupts both routine and major operations alike. These are the airline industry, the shipping industry and the armed forces. The airlines and their associated service facilities have a responsibility to their stockholders to show a profit and to the public to provide a safe and convenient service. With regard to the airlines, the twenty busiest airports in the United States are closed for a long-term average of 2700 hours each year at an annual cost of approximately seventy-five million dollars (Beckwith, 1968). The armed forces are responsible for the protection of the people and the government of the country, without regard to meteorological phenomena. Consequently, the airlines and the government have invested considerable sums of money in the study of fog and its possible modification.

Resultant research led to effective and practical means of dissipating supercooled fog by exploiting its unstable nature, a result of the liquid water droplets in an environment below freezing. Frozen nuclei and their subsequent rapid growth are provided by the use of propane, carbon dioxide, silver iodide, lead iodide, or dry ice. But only five percent of the heavy fogs which disrupt air operations in the contiguous United States are supercooled (Beckwith, 1968; Osmun, 1969). Thus, the problem of fog and its modification remains largely unsolved. It is toward this problem that this paper is aimed.

II. WARM FOG DISPERSAL

A. PRINCIPLES OF DISPERSAL

Since the publication of Houghton and Radford's landmark work (1938), most fog investigators have generally accepted their classification of the principles upon which all fog dispersal methods must be based. These are: (1) evaporation of the suspended water droplets and (2) physical removal of the droplets from the aggregate.

The principle of evaporation is not directly operable. It requires an intermediate process to reduce the relative humidity of the parcel below its equilibrium level before evaporation may proceed. This can be accomplished by one of two processes. The most direct, and the most successful to date, is the application of heat. A heated air parcel has an increased capacity (Table I) to hold water vapor; therefore, if no moisture is added to the parcel in the heating process, the relative humidity is automatically reduced. The suspended fog droplets then commence the process of evaporation.

TABLE I

Pressure and density of saturated water vapor

Temperature (C)	0	10	20	30	40
Vapor pressure (mb)	6.1	12.3	23.4	42.4	73.7
Vapor density ($g\ m^{-3}$)	4.8	9.4	17.3	30.4	51.2

The second manner in which the principle of evaporation becomes operative is by an actual reduction in the water vapor of the air parcel.

This constitutes a reduction in the relative humidity as before, and the same results are obtained at a lower temperature. For this purpose, hygroscopic agents, or dessicants, may be introduced into the air parcel to extract its water vapor by absorption. Since the water vapor content of a warm fog is normally much greater than the liquid water content (assumed constant at 0.2 g m^{-3}) a relatively small reduction in the vapor will produce a sufficient imbalance in the vapor pressure to cause droplet evaporation and, further, maintenance in the vapor phase.

Application of the principle of physical removal of water droplets has occupied considerable attention of investigators because it holds the promise of a rapid and direct means of fog dispersal. The possible techniques are more numerous and varied than for evaporation. Among the applicable techniques are: (1) entrapment of fog droplets, (2) mechanical sweeping away of the fog droplets by particles introduced for that purpose, (3) modification of droplet coalescence so that an appreciable number will attain precipitable mass and fall out, (4) application of an electric field to produce precipitation, and (5) production of charged particles in the fog to take advantage of naturally occuring atmospheric electrical forces.

In this paper, the above methods and variations on them are examined to determine how they have been applied, what success has been achieved, and their potential for further research and/or application to operational use. A tabular summary is included in Appendix A.

B. APPLICATION OF THE PRINCIPLES OF WARM FOG DISPERSAL

The following discussion considers proposals and methods and, where applicable, results of these methods when applied to fog dispersal tests. In many cases, nothing new can be added to previous surveys except an opinion regarding the potential of the method, in light of more recent related research. In other cases, research into the method is still in its early stages and little is known about its effectiveness; hence, any research into these methods is significant.

As in all research, conclusions are demanded regarding the various methods and their ultimate value. Since the most urgent need for fog dispersal stems from aviation, a criterion for the success of a method is its ability to clear and maintain a clearing in the vicinity of a fog-enclosed airport sufficient to meet the minimum standards of the Federal Aviation Administration for instrument operations. These minimums are a ceiling of no less than 200 feet and/or a horizontal visibility of no less than one-half mile (60 m and/or 800 m) at the runway. To attain this goal, a considerably larger space must be cleared to allow for diffusion, filling, and unpredicted wind behavior. Ideally, this clearing should be one hundred meters in both height and width and two thousand meters in length, a volume of 2×10^7 m^3. This region, oriented along and centered laterally over the duty runway defines the landing zone as used in this paper. A method which cannot adequately clear the landing zone of fog is thus not considered suitable for routine operational use.

A further requirement is dictated by the prevailing wind. Duty runway selection is a function of the physical configuration of the airport and the wind direction. Since it is rare that the prevailing wind is exactly parallel to the runway, a tunnel clearing as produced by Houghton and Radford (1938) downwind of their spray installation is of little practical value because of the crosswind component. This component, perpendicular to the runway axis, tends to cause a drift of the cleared zone out of its desired location. The amount of displaced volume from the landing zone equals 2×10^5 m^2 times the crosswind velocity. Thus, a crosswind of 5 m sec^{-1} would require clearing at the rate of 10^6 m^3 sec^{-1}, a volume greater by a factor of 500 than that of Houghton and Radford.

In order to discuss the various methods quantitatively, the coastal fog model developed by Jiusto (1964) is used with modification (Table II). Based upon this model, the total liquid water content of the landing zone is 4000 kg. A crosswind of 5 m sec^{-1} would require the removal of water at the rate of 200 kg sec^{-1}.

TABLE II

Model of coastal advection fog

Parameter	Magnitude
Range of r (μ)	3.0 - 32.5
$\bar{r}$ (μ)	10.0
W (g m^{-3})	0.2 (1)
N (cm^{-3})	40
Vertical depth (m)	50 - 600
Nuclei radius (μ)	0.5 (2)
Notes: (1) constant with height in lowest 100 m (2) chlorides and nitrates	

The actual amount of water which must be removed is something less than the above, depending upon the method of removal employed. Since the objective is an improvement in visibility, it is important to note the manner in which V depends upon W and the fog model. This may be seen by an examination of a simplified form of Trabert's formula for visibility as discussed by Buxton et al. (1968), Neiburger (1953), and Pilié (1966) in which

$$V = 2.6\ k\ \rho_w\ \bar{r}/W \tag{1}$$

where k is a function of droplet-size distribution but generally equated to 1.2. The radius $\bar{r}$ in μ, water density ρ_w in g cm^{-3}, and liquid water content W in g m^{-3} yields the visibility V in meters. Thus, an improvement in visibility will result from a shift in the droplet-size spectrum toward the larger droplets with little or no change in W. Similarly, a decrease in W is seen to produce an increase in visibility. If all the larger droplets were removed, both $\bar{r}$ and W would be reduced but the change in W would dominate. On the other hand, if the smaller droplets were eliminated, then the resultant increase in $\bar{r}$ would dominate. Thus, one approach to the problem is to produce a shift in the droplet-size spectrum. Such an approach is based upon the principle of evaporation. Physical removal, on the other hand, favors the larger droplets rather than the smaller and for this reason tends to operate primarily upon W in order to obtain the desired improvement in visibility.

It is thus seen that an improvement in visibility does not require, necessarily, removal of a large quantity of water. Further, water elimination is a function of the method of approach and its underlying principle.

1. <u>Physical Removal of Water Droplets</u>

As mentioned earlier, there are five major methods by which the water droplets of fog may be physically removed. These are: (a) entrapment, (b) mechanical sweeping, (c) modification of coalescence, (d) application of an electric field, and (e) introduction of charged droplets. These methods will be discussed in the above order. In addition, there are methods which overlap the above divisions. These will be discussed under the primary headings and only mentioned under the secondary headings.

There was one reported proposal in addition to the above which advocated the replacement of the entire air parcel with the drier air from above the overlying inversion (Houghton and Radford, 1938). The problems associated with such a scheme are insurmountable. The fallacy lies in the absence of lateral boundaries which would be necessary to contain the forced vertical exchange. This is not to state that vertical air exchange would be of no value or is not possible. To the contrary, vertical exchange has been demonstrated as an effective means of removing fog under certain circumstances. This approach will be discussed under the heat methods.

a. Entrapment Methods

The methods included in this category are generally of an impractical nature. Each is sound in basic principle and each could be made to work if one were faced with the simple task of removing fog droplets from a given small volume of air and if there were no restrictions on the type device to be used or where it could be located with respect to the volume of air to be processed. It will be shown, however, that none of the methods are feasible for clearing the landing zone because of the large volume of air involved and because of the hazards to air operations which would result from the necessarily gigantic installations.

One of the earlier schemes suggested drawing the fog-laden air through underground ducts (Houghton and Radford, 1938). where the water droplets would be caused to condense on screens or baffles after which the air would be discharged to the atmosphere. The drier air would still be at or near saturation upon its discharge. Thus, the vertical motion imparted to the air as a consequence of its egress from the tunnel would tend to nullify the effects of the water removal. In addition, the turbulence created by air discharge would also tend to cancel out the beneficial effects through increased mixing with unprocessed air. In a recent test of the basic principle involved, Schmieschek (1967) used a small mobile device consisting of a wind tunnel, 5 m in length and 2 m in diameter with a built-in fan and a counter-rotating metal sieve. The purpose of the sieve was to capture the water droplets while offering the minimum of resistance to the air flow. The fan served to move an air column through the tunnel at a velocity of 6 m sec^{-1} in the absence of local wind and was capable of turbulent effects at 80 to 100 m from the tunnel exit. Tested in fog with an initial visibility of 20 m, the device caused an increase in visibility to 80 m along the air-jet axis. After shutdown, the cleared region quickly filled, confirming the temporal nature of this type of fog dispersal in the presence of turbulence and dense fog.

Various types of fixed obstacles have been suggested for trapping the water droplets. One of two principles is applicable in each case. The first is that a moving droplet will be collected by any physical barrier which it encounters. Droplet removal by this means requires a barrier as large as the entire cross-sectional area of the wind-driven air. The second principle is that air, if forced to change its direction of travel, will do so readily whereas suspended droplets change direction much more slowly because of their greater inertia. Hence, in an application of this principle, the droplets strike the baffle walls where they are collected and drained off. Both of these principles require a propelling force for the air, either a mechanical device or the wind. Among the baffles suggested are trees and vegetation (Hori, 1953) and giant screens of various sorts.

The disadvantages of baffles and screens are beyond acceptance for a landing zone. Their physical size and the permanent nature of the installation prohibit use near an airfield. Additionally, they create self-defeating turbulence, and are useless under calm or very light wind conditions. In most cases, only the larger droplets would be collected because of their greater inertia; thus, only a relatively small improvement in visibility could be anticipated. Finally, since the relative humidity would remain unchanged by this process, the entire volume of air would require treatment.

b. Mechanical Sweeping Methods

Mechanical sweeping as used in this paper is the process of collecting fog droplets by giant particles or water droplets introduced into the fog from aloft for that specific purpose. It is analogous to the entrapment method of placing a barrier in the path of every fog droplet within the air parcel. In the same manner, this method is often grossly over-simplified.

Mechanical sweeping depends upon several parameters: droplet-size distribution and concentration, liquid water content of the fog, size of the sweeping bodies, their fall velocity and relative velocity, their spatial distribution and their collection efficiency.

Although the latter parameter is frequently overlooked or assumed to be unity as an expedient, Langmuir (1948) showed that the collection efficiency ranges from 0 to 95 percent, depending upon the sizes of the sweeping body and the water droplet. Thus, caution is required in a quantitative approach to this method.

In an application of mechanical sweeping, a recent feasibility study was made of the use of seawater to clear fog over the ocean (Buxton et al., 1968). The study envisioned a rotor system, mounted upon a naval escort vessel, capable of lifting the seawater to a height of 60 m in a uniform spray of 100 μ droplets at a flow rate of 12.6 liters sec^{-1}. It was concluded that a rotor 6 m in diameter would produce a single-drop monolayer of seawater over a 7.6-m circle at the surface with near perfect coverage. Visibility was predicted to improve by a factor of two to three for a single-drop monolayer and by a factor of up to eight for a two-drop monolayer. Calculations showed a requirement for six escort vessels, each carrying two of these rotors, to clear a corridor, 100 m by 8 km within a time of 26 minutes, assumed sufficient for aircraft carrier launch and recovery operations.

Based upon the study, its assumptions, and the above calculations, the method is not considered practical for routine operational use. In addition, the carrier would operate at greater than twice the recommended maximum speed of 10 kt for the spraying vessels; therefore, any such operation would be limited to a very few aircraft. It is entirely possible, however, that if a prototype system were constructed and produced the predicted results, it would be applicable for other purposes, such as refueling, underway replenishment, and harbor clearing.

Among the other investigators who have examined this method are Houghton and Radford (1938). They calculated that the release of water drops of 100 μ radius from a height of 10 m would require a water flow rate of 13.3 kg sec^{-1} (or liters sec^{-1}) to clear a volume of 2000 m^3 per second in a wind of 5 m sec^{-1}. This quantity was a theoretical minimum and it was assumed that at least twice that rate would be required in actuality because of uneven distribution of the water drops in both size and space.

Plank (1954) also examined the method of water sweeping. Although his study evolved from an examination of another principle, he showed analytically that a 16 percent improvement in visibility could be obtained by seeding with water droplets from aloft. This was based upon an aircraft speed of 132 knots (68 m sec^{-1}), a strip coverage of 30 m, water droplets of 100 μ radius, and a water flow rate of 750 gal min^{-1} (47.3 liters sec^{-1}). His calculations led to the conclusion that although the method is possible, operational use would require four aircraft full time to clear and maintain the clearing for air operations at an airport. Thus, it was concluded that other methods would be more practical.

The same approach entered into the work of Magano et al. (1963). Although their results were claimed to be from an induced vertical air exchange and are more fully discussed elsewhere, it is considered certain that the sweeping action of the water droplets made some contribution to the observed breakup and dissipation of stratus clouds. In this particular experiment, there were a number of unknowns which were neither controlled nor monitored. Hence, little can be gained from its discussion, particularly with regard to mechanical sweeping.

Other mechanical sweeping methods require the use of electrically charged water droplets or sand particles. Since the primary factor in their use is an increase in the effective cross-sectional area of the particle or droplet due to electrical forces, these will be discussed later.

A final suggestion, reported by Junge (1958), is the use of hydrogen filled soap bubbles. While the idea is certainly fascinating, it is intuitively obvious that such a scheme is doomed from conception by its impracticality.

Review of mechanical sweeping methods illustrates the point made earlier with regard to caution in considering these methods quantitatively. The water requirement of Buxton et al. (1968), is five times greater per unit area covered than the theoretical minimum of Houghton and Radford (1938) but is only fifty percent greater than that of Plank (1954). On the other hand, the predicted results are greater by an order of magnitude. Two factors enter here. In the first case, Plank calculated that his flow rate was the maximum which could be applied without overlapping the spray droplets and producing undesired coalescence between them, whereas Buxton introduced some overlap into his calculations in order to compute for total coverage. The other factor lies in the calculated quantities of water which could be removed by this process. Direct comparison is not practical since the fog models were considerably different. Similarity in their conclusions as to possible results is of more importance than the details of disagreement.

In spite of the more recent study, there has been no significant change in the status of mechanical sweeping since Wayne and

Bell (1953) concluded that although it is frequently proposed, it has little support as a method of warm fog dispersal.

c. Coalescence Modification Methods

Coalescence is a term frequently used to designate a category of dispersal methods. It is the process of combination of two liquid droplets as a result of collision between them (Huschke, 1959). As a result of the combination, the number of droplets is reduced and those that remain are larger. Both of these factors produce an increase in visibility. In principle, the larger droplets precipitate out of the foggy air and improve the visibility still further. This depends, however, on a number of factors including the initial size distribution, wind condition, and fog layer thickness. The definition as given excludes the growth of hygroscopic particles and droplets resulting from a vapor pressure differential. Similarly, certain electrical methods affecting coalescence are excluded and discussed separately. Hence, there remain only two general methods in this category.

As indicated by Jiusto (1964), collision between droplets or particles in the atmosphere can occur as a result of random motion or aerodynamic interaction, the latter arising from their different velocities. He showed that this process is negligible. By use of an extension of the Smoluchowski theory of particle agglomeration,

$$\frac{dN}{dt} \approx 10^{-6} N^2 \left(1 + \frac{10^{-5}}{r}\right) \tag{2}$$

where r is the droplet radius in centimeters and dN/dt is the number of collisions occurring per hour in one cubic centimeter. Using typical values of droplet size and concentration from his fog model, he found dN/dt = 0.04, which is certainly insignificant. Similarly, the aerodynamic effects are also small with respect to the dissipation of fog.

Fig. 1 shows the collection efficiency (E) for water drops falling through the atmosphere. It is readily seen that E approaches unity for larger drops but these are rare within the fog. Further, it should also be noted that the high collection efficiency descreases to zero with respect to the smaller fog droplets. Thus, it is seen that if physical removal is to be brought about by coalescence, both the rate of collision and the collection efficiency must be increased.

The coalescence methods to be considered depend upon either sound waves to produce an increased droplet collision frequency or the behavior of surface active substances to modify the characteristics of water droplets. It will be shown that whereas surfactants show promise for study and exploitation, sound fields show none.

In the case of the sound field theory of coalescence, it has been shown that the forces within the field are very complex but are essentially of three types (St. Clair, 1949). These are covibrational forces between the particles and the surrounding gas, hydrodynamical forces of attraction and repulsion between the particles, and radiational pressure forces. Covibrational forces result from the behavior of particles of different masses, suspended in a gas, when subjected to an intense sound field. At a given frequency, the particles vibrate at different amplitudes. The smallest ones vibrate at an amplitude approaching that of the gas while the larger, heavier ones remain relatively stationary. Thus, the collision frequency should be considerably increased if the sound field could be adjusted to produce, on particles of average mass, an amplitude of vibration of the same order of magnitude as the average distance between particles (Houghton and Radford, 1938). The field strength required to produce

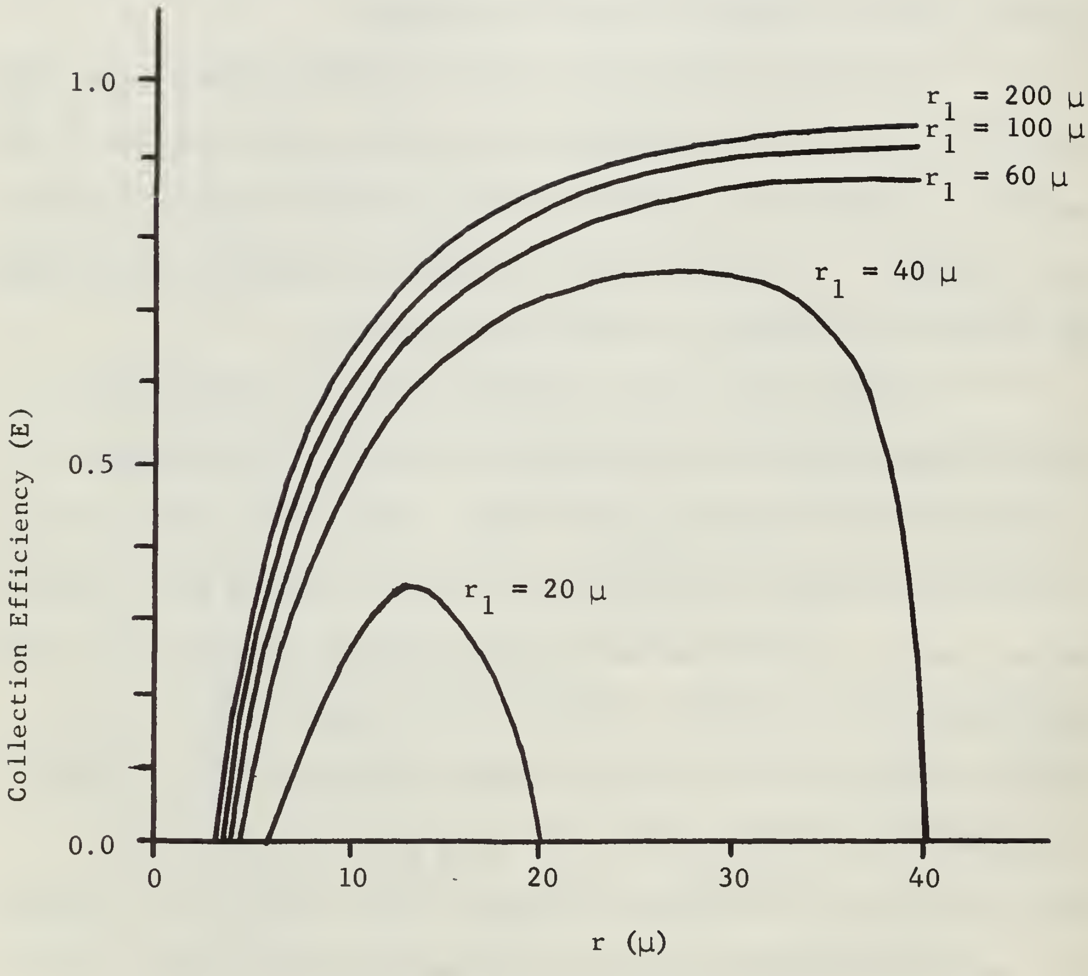


Fig. 1. Collection efficiency of falling water drops. Curves correspond to the efficiency E with which drops of radius r_1 collect droplets of radius r. (After Buxton et al., 1968).

adequate oscillatory motion in fog droplets is extremely large and within the audible range, approximately three kilohertz. Hence, it has been repeatedly discounted as being beyond practical limits (Houghton and Radford, 1938; St. Clair, 1949; Wayne and Bell, 1953; Junge, 1958; Stewart, 1960). Similarly, it has been shown that the hydrodynamic forces are normally very small, much less than gravitational forces acting upon the droplets (Houghton and Radford, 1938), and important only when the distance between particles or droplets is no more than a few particle diameters (St. Clair, 1949). Assuming a fog droplet concentration of 200 cm^{-1}, mean separation would be 0.17 cm, or approximately 100 diameters. Thus, the actual hydrodynamic forces involved would be several orders of magnitude below the threshhold of effectiveness since they are inversely proportional to the fourth power of the distance between centers (Houghton and Radford, 1938; St. Clair, 1949). Certainly, such small forces can be ignored in fog. Only the radiational pressure forces are believed to be important in accounting for the observed coagulation (St. Clair, 1949) of smoke and dust in a resonant chamber. When a sound field was established inside, the radiation pressure tended to drive the particles to the antinodes of the standing waves, increasing the particle concentration in those regions. Thus the chances for the rate of collision were increased in the antinodes. Further, because of the increased concentration, the previously mentioned forces also became more important. In later experiments with a small resonant enclosure, St. Clair demonstrated that a small water droplet could be supported against gravity at a frequency of 10 kilohertz at an energy density of 400 ergs cm^{-3}. This demonstration cannot be extrapolated to fog dispersal in open space, however, because the production of standing waves is possible only with suitable reflective boundaries. Even if adequate boundaries could be established, one is led to the conclusion that sonic coalescence of fog water droplets is not practical because of the large energy requirements and the hazards to personnel.

Surfactants, on the other hand, show promise although the nature of the process is not clearly understood. Essentially, surface active materials consist of long organic molecules whose opposing ends react differently in the presence of a solvent. Typically, one end is wettable and the other is non-wettable. Thus, the molecule seeks the surface of a solvent such as water and orients itself so as to remain partially wet and partially dry. As a result, the concentration of the surfactant is greatest at the surface and a monomolecular layer is formed (Pilié, 1966). It was originally believed that because the monomolecular layer reduced the surface tension of water droplets, coalescence would be enhanced (Berg et al., 1963; Jiusto, 1964; Beckwith and Flynn, 1968). It has been demonstrated, however, that although surface tension was in fact reduced by as much as 60 percent, coalescence of water drops with a plane surface was not enhanced, but was actually retarded (Jiusto, 1964; Pilié, 1966). The exact nature of the process whereby the use of surfactants leads to increased precipitation is still unknown. It has been suggested by Jiusto (1964), however, to be a result of the irregular shapes that the droplets may assume as a consequence of the reduced surface tension. Another possibility is that although the monomolecular layer inhibits growth by diffusion or condensation, the droplet may still grow slowly and eventually break down the surface layer. If this occurs, extremely rapid growth should follow because of the size then attained, a possible vapor pressure differential in this environment, and a relatively small number of droplets in competition for available water vapor. The result should be a few large droplets precipitating from the fog. This was observed by Bigg, Brownscombe, and Thompson (1969) in a fog retardation experiment in Australia; however, no conclusions about the nature of the process could be established.

In addition to the above, ionic surfactants (or polyelectrolytes) separate into oppositely charged ions when in solution. In this way, a charge of one sign is concentrated on the surface of a droplet and the opposite charge is contained within. The overall charge on the droplet remains unchanged (Pilié, 1966). Recent work has centered around the application of various polyelectrolytes. The most comprehensive tests have been conducted by World Weather, Inc. of Houston, Texas, under contract to the Air Transport Association of America (Beckwith and Flynn, 1968). In these tests, surfactant materials were dispensed by aircraft in both powder and liquid form at Houston and Sacramento (Osmun, 1969) for the purpose of demonstrating that closed airports could be opened for traffic by means of the World Weather, Inc. fog dispersal method. The reported mechanism of dispersal was the production of small-scale local instability by the seeding materials and, subsequently, precipitation. This was based upon the belief that surfactants served to increase coalescence. Regardless of the exact process, droplet growth was produced, as evidenced by pilot reports of larger drops and more water on their windshields on successive passes through the fog layer (Beckwith and Flynn, 1968). Furthermore, in approximately seventy-five percent of the actual tests, closed airports could be reopened for operations as a result of the clearing produced. In other tests for the same organization, a mobile apparatus was used to dispense the seeding agent from the ground. Capable of reaching heights of 60 m, it was reported to produce observable effects in two of four trials at Sacramento and in three of four trials against sea fog at Nantucket on Cape Cod (Osmun, 1969).

Except for the degree of success attained, no evaluation can be made regarding the methods or the materials. In all cases, a commerical organization was involved. Information regarding the tests, excluding the final results, was considered by the contractor to be proprietary in nature and was therefore not released. There were complicating factors in the tests. The agents used were reported to be both ionic and non-ionic surfactants in various forms and were compared to a reference method of vaporized salt brine. It was also reported (Beckwith and Flynn, 1968) that in every case, the material was either an ionic agent or it was ionized upon discharge into the fog. There are simply too many unknowns involved for proper evaluation, even if complete details were known. These tests provide a classic example of the need for interactive research into weather modification (Rand Corp., 1969), fog modification in particular. Without this tests proceed at random, sometimes without sound physical bases, permitting little if any knowledge to be gained from the results. As things stand, it appears that the necessary research into all methods of fog dispersal must be conducted in the interest of pure science or under government sponsorship, if the results are to remain in the public domain.

d. Electrical Methods

Since the atmosphere contains ionized particles and measureable electric fields, it is natural that many proposals would be made to capitalize on these phonomena in the removal of water droplets. There are two classes of such proposals: 1) application of a strong electric field and 2) introduction of additional charged particles or droplets. In both cases, the object is to produce an increased rate of collision and collection and/or precipitation. These are reasonable in theory but experimentation has been unsuccessful except in the laboratory. Various investigators (Houghton and Radford, 1938; Jiusto, 1964; Junge, 1958; Pilié and Kochmond, 1967) have concluded that because of the inherently small charges on the naturally occurring fog droplets and the small mass of each, creation of an electric field sufficiently large to have an appreciable effect on coalescence or to produce precipitation is not reasonable in the field although it has been demonstrated in the laboratory by Arthur D. Little, Inc. (1956) and Plumlee (1964).

The production of charged droplets in space has been more closely examined by others. The Cottrell method of producing charged droplets of like sign by corona discharge was examined by Houghton and Radford (1938). It was shown that the production of the desired clearing at the rate of 2000 m^3 sec^{-1} would require a wire 50 m long, at a height of 10 m and at a potential of six megavolts. The drawbacks to such a system with respect to physical and electrical hazards are obvious. In addition, there is the practical problem of having available electrical energy of this magnitude on an as-needed basis. Hence, their conclusion was that it was not a practical solution to the dispersal of fog. Arthur D. Little, Inc. (1956) reported some success in the laboratory resulting from droplets charged by corona discharge but none in the field. Similar results were obtained by the Armour Research Foundation which studied corona discharge as a means of charging a sprayed seeding agent (Lieberman, 1960). While the results were generally inconclusive, the method was confirmed.

Such proposals have continued, however. A more recent one by MacCready and Mee (1965) suggested corona discharge from opposite wingtips of an aircraft flying through the fog layer, producing two paths of charged droplets, opposite in sign. These would trail behind in parallel lanes only a few meters apart and would gradually, through attraction, coalesce. As many passes as required could be made to clear the fog from a lane of any desired width, if the scheme were practical. In the sense that this proposal considers unlike charges in closer proximity, it is an improvement over earlier ones which considered the creation of like charges only whose mutually repulsive forces were expected to drive the water droplets out of the region. Regardless of the improvement in concept, it also appears unworkable. Pilié and Kochmond (1967) followed up a suggestion of Pilié (1966) to produce corona discharge using alternating current, creating charged droplets of both signs within a region. They found that the attractive force between oppositely charged fog droplets, 10 μ in radius, was eight orders of magnitude less than the force of gravity and therefore of no significance in the production of coalescence.

Of more interest because of its greater potential for success is the method of introducing charged particles to sweep out the water droplets. It was reported by Houghton and Radford (1938) that earlier calculations indicated charged grains of sand 100 μ in diameter would have effective diameters of 380 μ in sweeping out fog droplets if the maximum possible charge was carried by each. Although distribution would be an important factor and the production of the charged particles might be difficult, the potential for success is present. Later investigators have also concluded that the method is feasible. Pauthenier (1950) showed that the use of charged water droplets vice uncharged droplets would result in an increase in the effective diameter of the droplets by a factor of 100, provided that each droplet carried the maximum possible charge. Experimental verification of these calculations would be both helpful and enlightening.

Use of an electric potential gradient in another manner was attempted by Hagen (1961). His efforts were concerned with the production of induced vertical mixing as a result of an ionic current from a long wire at a high potential, located above an inversion. After failing to produce any discernible effects other than a space charge over a large area of the experiment site, testing was terminated and the experiment re-examined. As a result of mathematical analysis, it was concluded that it would not be feasible to produce a downdraft by an ionic current in this manner.

With similar results, Lieberman (1960) reported various tests based upon electrical properties. As mentioned previously, little was gained through the study of corona discharge. Electrical enhancement of coalescence was demonstrated in the laboratory using large water drops. Satisfactory charging of a sprayed mist by electrostatic means was also demonstrated (and proved to be a superior method, as compared to corona discharge). This method also proved inconclusive in the field. Two different triboelectric powders were used as seeding agents in laboratory fogs. It was stated that the only discernible effect of these powders was to stabilize some fogs.

The final method to be considered in this category is that of the ionic surfactants which alter the electrical characteristics of the droplets. Considerable work remains to be done before any quantitative answers will be known. Proponents of the method are enthusiastic and have achieved some success in mixed methods but evaluation is extremely difficult. In the Sacramento tests reported by Beckwith and Flynn (1968), for example, the agents used were undisclosed surfactants and salt brine. They were reported to be either ionic surfactants or were ionized upon discharge in every case. Without knowing the nature of the materials used, little can be said about them. In the case of the salt brine, however, it has been demonstrated that a hygroscopic solution is itself an effective agent under certain conditions. The question to be resolved is how much of the observed success, about 75 percent in opening closed fields, was the result of ionization. The conclusion of the Cornell Aeronautical Laboratory study (Pilié, 1966) is that the ionic surfactant has not produced any increase in the coalescence of water droplets in the laboratory. On the contrary, coalescence was actually reduced by surfactants, regardless of their ionic nature. In spite of this, no case is known of a field test in which the fog was actually stabilized by an ionic surfactant as was reported by Lieberman (1960) in laboratory tests.

In view of the foregoing uncertainty and lack of consistent results, it appears that fog dispersal based upon electrical properties is an area for additional study, but only with respect to mechanical sweeping by charged bodies and the use of ionic surfactants. The latter appears to be a method in which the results are easily tainted by uncontrolled conditions; therefore, extreme caution must be exercised before final conclusions are reached. Similarly, the question of control arises in regard to the stabilizing effect noted by Lieberman. This points up a crucial factor in warm fog dispersal--an understanding of the physical processes involved. It appears that since the stabilizing occurred in the small fog chamber, the cause was most likely overseeding in a limited volume. The same effect has been produced by various investigators by overseeding with small hygroscopic particles. The result is simply that there is not enough water available to permit droplet growth to precipitible proportions.

2. Evaporation of Water Droplets

The principle of evaporation of water droplets to achieve the dissipation of fog may be applied in either of two general ways: a) by the application of heat to the air so as to increase the air temperature and thus increase the capacity of the air parcel to hold water vapor or b) by dessication, the direct reduction of the actual vapor density of the air parcel. Either method of approach is capable of achieving the same result, a reduction in the relative humidity. Consequently, the suspended water droplets may then evaporate because of the vapor pressure differential. Since the vapor content of a saturated air parcel is much greater than the liquid content, a small change in the relative humidity will produce a sufficient reduction in the vapor pressure to permit a considerable reduction in the liquid content and, hence, an improvement in the visibility.

To appreciate the significance of the evaporation process to the problem of fog dispersal, it is necessary to understand how the evaporation of the smaller droplets is favored. Fleagle and Businger (1963) related the saturation vapor pressure e_c over water droplets to that over a plane water surface, e_s, by

$$e_c = e_s \exp (2\sigma/r\rho_w R_v T) \tag{3}$$

where R_v is the gas constant and T is the temperature. If it is assumed that the surface tension (σ) on a droplet is essentially constant then Eq. (3) may be rewritten

$$e_c = e_s \exp (\text{const}/r\ T) \tag{3a}$$

which illustrates more clearly the dependence of e_c upon r. It is thus seen that e_c may be extremely large compared to e_s over the smaller droplets. Hence, because of the vapor pressure differential, the smaller droplets evaporate more readily. Furthermore, because of the difference in the volume of the droplets, the smaller ones evaporate more rapidly. The spectrum of the size-distribution of the water droplets is thus shifted toward the larger sizes and the concentration of droplets is thus drastically reduced. The significance of this is the improvement in visibility which follows as a consequence.

a. Heat Methods

Just as other general methods are broken down into subgroups, it is convenient to discuss the application of heat in two categories, the direct application of heat to the air parcel and the production of heat in the air parcel by indirect methods. The object of either is to raise the air temperature sufficiently to decrease the relative humidity below saturation and promote droplet evaporation.

As stated, heat methods are based upon some means of supplying heat to the air parcel. The important question to be resolved is the amount of heat required. A precise answer is beyond the scope of this paper and, for the present purpose, of no more value than a reasonable estimate. Such an estimate can be made on the basis of the liquid content of the fog, the relative humidity, the temperature, the volume of the landing zone, the amount of water vapor added in the heating process, and the required rate of clearing which takes the wind into account. The heat required to evaporate the fog droplets is given by

$$H_w = L\, m_w$$

where L is the latent heat of vaporization and m_w is the mass of water. Based upon the assumed model fog with 2×10^7 m^3 in the landing zone, an ambient temperature of 10C, and a relative humidity of 100 percent, the heat required to completely evaporate the liquid water content of the fog is

$$\begin{aligned} H_w &= (594 \text{ cal g}^{-1})\ (0.2 \text{ g m}^{-}\ )\ (2 \times 10^7 \text{ m}^3) \\ &= 2.38 \times 10^9 \text{ cal.} \end{aligned}$$

Since the above assumes a change of state without a change in temperature, the air would be supersaturated and not be in equilibrium in the assumed situation; therefore, the air temperature must be increased to accommodate the additional water vapor. Fig. 2 shows that an increase in the vapor density by 0.2 g m^{-3} would require less than 0.5C increase in temperature. Taking a one-degree increase as a safety measure, one finds the heat required to increase the air temperature is given by

$$H_a = C_p\ \Delta T m_a \tag{5}$$

or

$$\begin{aligned} H_a &= (0.24 \text{ cal g}^{-1}\ {}^{o}C^{-1})\ (1.0^{o}C) \times (1.23 \times 10^3 \text{g m}^{-3})\ (2 \times 10^7 \text{ m}^3) \\ &= 5.96 \times 10^9 \text{ cal} \end{aligned}$$

where C_p is the specific heat of moist air and m_a is the mass of the air. Hence, the total heat required to evaporate the liquid water and

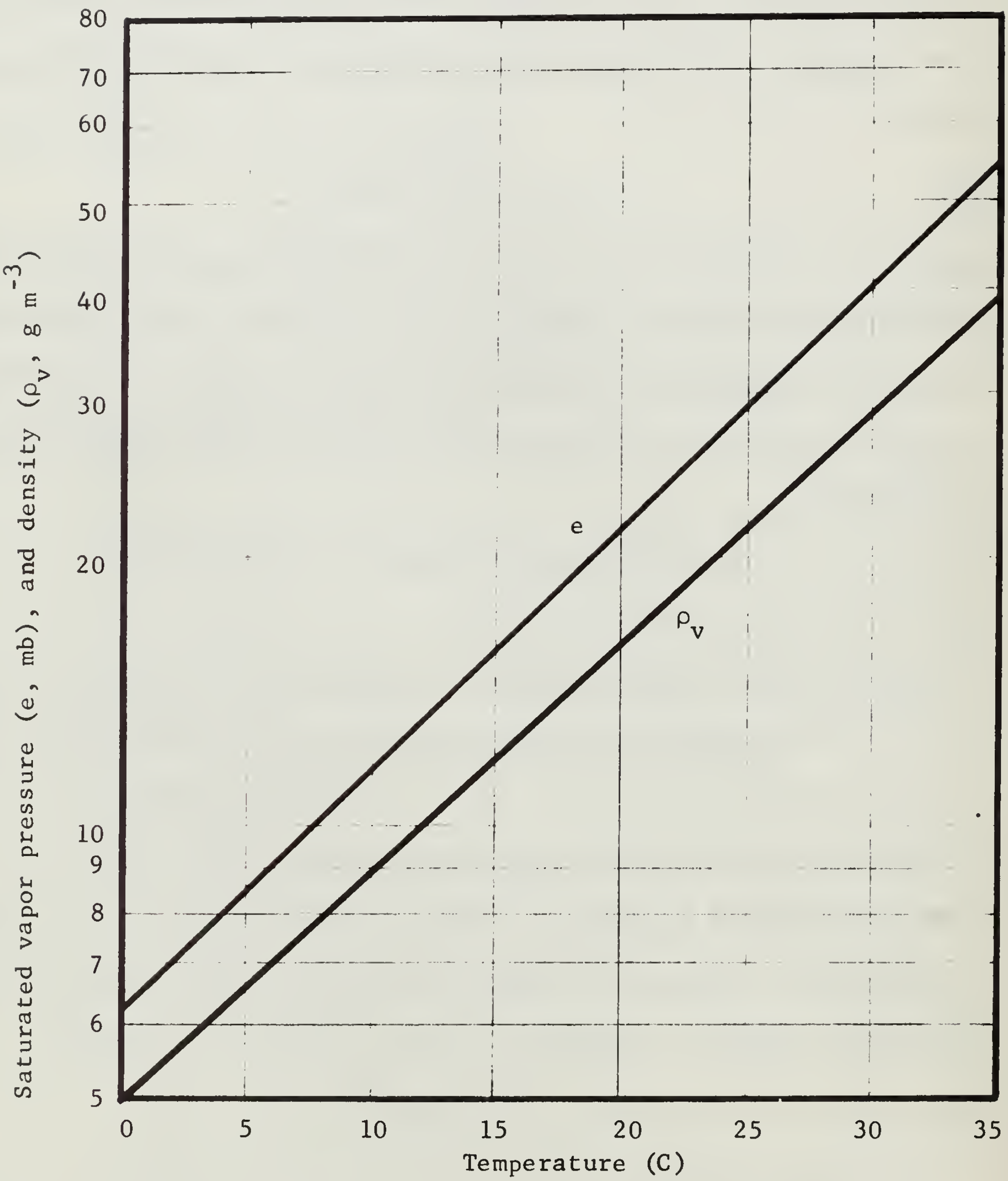


Fig. 2. Pressure and density of saturated water vapor. (After Beers et al., 1945).

raise the air temperature sufficiently to maintain equilibrium in the vapor state, assuming no vapor is added in the process is

$$H = H_a + H_w$$
$$= (5.96 + 2.38) \times 10^9 \text{ cal}$$
$$= 8.34 \times 10^9 \text{ cal.}$$

Since most practical methods of heating the air parcel will also add water vapor to the air, this factor must also be taken into account. A first estimate of the heat required is therefore obtained as above. The water vapor added in the process of supplying that amount of heat is then estimated and considered dispersed uniformly throughout the landing zone, yielding a new vapor density value and, hence, a new value for ΔT. This value substituted into equation (5) then gives a good approximation to H_a. This latter correction will be examined, as appropriate, in the following discussion.

(1) Direct Application of Heat. The thermal techniques of dissipating fog are often referred to as "brute force" methods because there is no denying their success if a sufficiently large quantity of heat is added to an air parcel. The term is more aptly reserved for the FIDO method than for the others since its effectiveness has been repeatedly demonstrated. The FIDO system derives its name from the project under which it was developed by the British in World War II, Fog Investigation and Dispersal Operations.

With considerable simplification, the system consists of a network of fuel lines which parallel the runways of the airport. At intervals along the lines, burners are located in which hydrocarbon fuel is burned to heat the neighboring air, directly and by convection. Considerable turbulence is thus created which, in turn, cuts the efficiency of the method. The system is only in operation for short periods of time and is shut down during actual aircraft operations because of the fire hazards involved. Thus the heating is necessarily more intense with a resultant decrease in efficiency due to turbulence. It was estimated by Downie and Smith (1958) that 10 - 15 percent of the energy is lost immediately through radiation outside the desired region. Further, an unknown quantity is lost from the region through undesired turbulence and convection. In spite of this, a number of installations have been made in England, and two in this country, for the purpose of testing and evaluating the method. The two United States installations at the Landing Aids Experiment Station, Arcata, California and at the Los Angeles International Airport have since been abandoned. The Arcata facility was closed down presumably as having served its purpose. The Los Angeles installation was discontinued because it failed to dissipate warm fog under all conditions. Specifically, it failed in a particularly dense fog and it was subsequently decided that the system was not yet operational and, therefore, not suitable for further use at a busy field where unfounded dependence upon the system could be disasterous.

The advantage of the method is that is has been proven generally effective. On the other hand, it has a number of disadvantages. The initial cost is great--estimated at one to two million dollars by Downie and Smith (1958). The operating costs range between $65.00 (Macdonald et al., 1949a) and $150.00 (Downie and Smith, 1958) per minute of burn time. (This is generally considered excessive as compared to other possible methods.) In addition, vast quantities of additional nuclei are released to the atmosphere. These could create additional visibility problems at a later time as, for example, after a wind shift. A certain amount of water vapor is also released, although this is generally considered insignificant as compared to that evaporated, except in the case of cold, dense fogs.

An examination of the water vapor added to the air through the combustion process reveals that this generality may be misleading. Considering the present fog model and the heat requirements as calculated, 8.34×10^9 calories and assuming 75 percent efficiency, the heat output would have to be at least 1.11×10^{10} cal per (5 min) burn. Downie and Smith (1958) reported that FIDO operation adds about one pound of water per 15,000 BTU of heat, or one gram of water for each 8300 cal. In this case, 1.34×10^6 g of water vapor would be added. If all the water remained within the landing zone, the added vapor density would be 0.067 g m^{-3}, or one third the fog water initially. It should be noted in this case that Fig. 2 shows the assumed $\Delta T = 1C$ is still valid, because it contained a safety factor. Another factor supporting the generality of "insignificance" is that because a large portion of the energy is lost from the landing zone through convection and turbulence, a proportional amount of the additional water vapor also escapes from the zone and the computed addition is therefore an overestimate. On the other hand, if the fog is colder than 10C or contains much more liquid water than 0.2 g m^{-3}, then much more heat will be required and, consequently, much more water vapor will be added. The added water can easily be equal to or greater than the initial water for cooler fogs, and hence, must not be ignored.

An alternate method of applying heat which avoids some of the disadvantages of the FIDO system is the use of turbojet engines as heat sources. Downie and Smith (1958) estimated that to produce the same effective clearing as a proposed FIDO installation at Thule Air Base, Greenland, fifty J-47 engines or twenty J-33 engines, operating at full power with afterburners, would be required. The fuel costs per minute would be approximately the same as for FIDO but the turbojet system has the advantage of flexibility. Both operational aircraft and surplus, stand-mounted engines have been proposed for this duty by various investigators. Although more flexible, the foreseeable operational problems with the system would be considerably increased in the case of operational aircraft. Offsetting any such additional problems, however, is the fact that study and evaluation of this method would not involve any large outlay of funds for heating equipment since the turbojet engines are reasonably available at the larger air facilities. As has been demonstrated at Travis Air Force Base using four C-141 aircraft (4 Pratt and Whitney TF-33P engines each) (Appleman, 1968; Coons, 1968b), visibility can be improved by this method. It remains to be seen what the optimum system design would be.

Turbojet engines have been studied extensively in France for the past decade. From 1958 to 1963, jet engines in different numbers were used at three French airports (Workman, 1968). Since 1963, studies of the TURBOCLAIR, or jet engine, system have been intensified at Orly airport. Among the techniques examined (Dubois, 1965; Fabre, 1968) is the location of the engines in trenches, 80 - 90 m from the runway centerline, and automatic, remote control. Exhaust deflectors have also been installed to give added flexibility. Combination of deflectors and trenches have reduced turbulence to a minimum by keeping the exhaust jet along the runway surface. The engines used include the

ATAR and the NENE. The former produces a total power output of 30,000 kw of which 80 percent is thermal energy. For the landing zone and conditions as previously described, this would require 33 such engines to produce complete dispersal at 100 percent efficiency. The model clearing of the French, however, contains considerably less volume than the one considered here and is probably much easier to attain except during a calm. Fig. 3 illustrates the model used by Fabre (1968). It is easily seen that in a light wind the ascending warm air would tend to produce a clearing of maximum height in the desired approach and transition (from radar control to visual) zones. Having a total volume of 6.5×10^{6} m^{3}, only one third as many engines would be required. Further, because of the model configuration, these should be somewhat more efficient, except along the runway where there would be considerably more heat lost from the top of the region than desired.

The most recent study of the jet system in the United States is an analytical one done by the U. S. Navy Weather Research Facility for use aboard aircraft carriers. Todd and Nickerson (1968) showed that a fog consisting of $W = 0.2$ g m^{-3} could probably be cleared from a cone trailing aft from the ship's bow such that the aircraft recovery glide slope would be in the clear for the final 300 m of the approach. It was further shown that this should be possible through the employment of 20 J-47 jet engines operating at 90 percent power from a location forward on the flight deck. It was suggested that the visibility might be improved through as much as the final 800 m of the approach with the aid of jet engines on or near the after end of the flight deck from where turbulence would produce downward mixing of the trailing heat plumes. Although the application of this concept raises

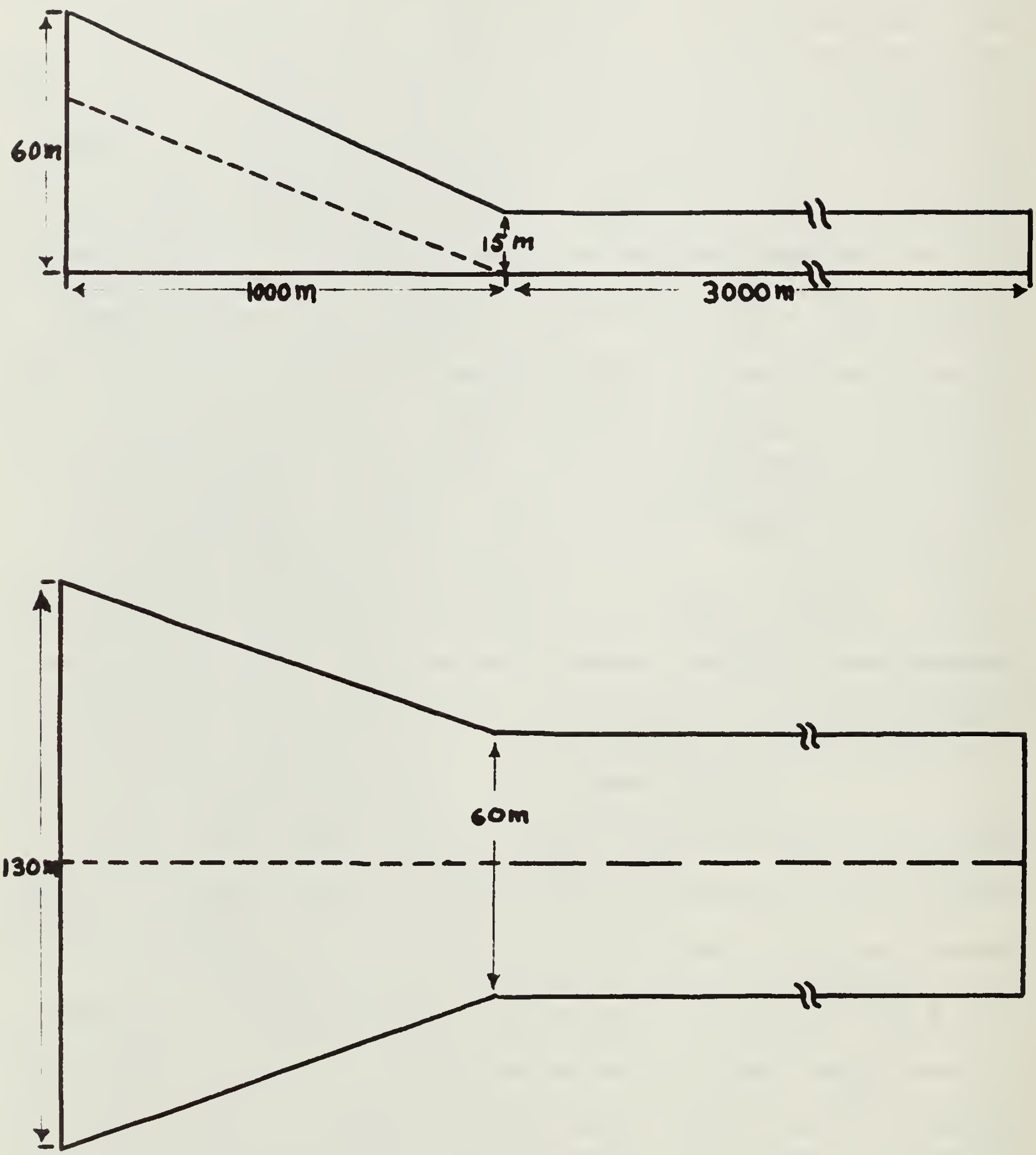


Fig. 3. Model clearing used by French investigators at Orly airport. Dashed line (---) is the aircraft approach path. The broken line (— —) is the roll-out and taxi path. (After Fabre, 1968).

many questions, particulary with regard to the rate of ascent of the heated air relative to the geometry of the glide slope, it is sufficiently sound to warrant actual testing at sea. The interacting factors of diffusion, turbulence, convection, and entrainment are too complex to permit definite conclusions without such tests.

In response to the same special problem of carrier aviation, a heat exchanger has been suggested for placement on the forward end of the flight deck of an aircraft carrier through which the air would pass. With proper design, it has been estimated by Wayne and Bell (1953) that if 20,000 hp were available for this purpose, such a heat exchanger could be capable of producing the desired clearing with 12 m^2 of heating surface per square meter of exchanger cross-section.

The heat exchanger was designed to present a cross-sectional area of 93 m^2 (15.24 m wide by 6.1 m high) to the airstream. Through its depth of 0.3 m, this was intended to dissipate 3.55×10^6 cal sec^{-1}. Assuming no heat loss through the framework and a relative wind speed of 40 kt (20.6 m sec^{-1}), the addition of heat would be 5.87×10^3 cal m^{-3} sec^{-1}. This would be more than adequate heating in the exit airstream but would be subject to turbulent mixing, diffusion, and slight convective vertical motion. Calculations were made to show that the system might produce a satisfactory plume of clear air trailing aft from the ship. This method would have the advantage of a lower plume of clear air than that produced by the CVA jet system previously discussed because of the lower operating temperature.

In spite of the physical soundness of the general concept, it is extremely doubtful that such a system could be made practical. One of the more important considerations is the hazard to personnel and the large amount of valuable deck space which would be lost through placement of the heat exchanger. Even more crucial is the power requirement which would be an added burden on the power plant at the very time when the greatest demand is being made for speed, during aircraft recovery operations in the lighter winds associated with sea fog.

The same power restriction is also valid in the case of another scheme for aircraft carrier use, the heated flight deck. Calculations by Wayne and Bell (1953) showed that the flight deck, heated to 100F (37.8C) by the assumed available 20,000 hp, would be ineffective as the sole heat source.

One of the earlier proposals for supplying heat to the air parcel suggested the ducting of hot air into the desired region from a central source. It has been shown (Houghton and Radford, 1938; Downie and Smith, 1958) that this is not feasible because the large volume of air to be transported would require impossible air velocities through the ducting.

Two other proposals reported by Wayne and Bell (1953) fall within this category of methods. These sought to avoid the turbulent losses by heating the water content of the air directly by radiation. One suggested electromagnetic radiation at any of the wavelengths at which the water droplets and water vapor are highly absorptive. As was stated then, the energy requirements are still far beyond the capability of present generating equipment in the necessary frequency ranges. The other proposal suggested the use of huge infrared radiators. It was calculated that a system could be constructed in two banks 3.05 m high and 1524 m in length and heated electrically. Such a system would require 2×10^8 watts to operate at an energy flux density of 21.5 kw m^{-2}. Because of its bulk and high operating temperature, it would represent yet another hazard to personnel and air operations. Further, the power demands are excessive. Consequently, it is considered that neither of these methods is practical and worthy of further consideration.

(2) Indirect Application of Heat. The indirect approach would avoid the addition of large quantities of heat to the atmosphere and the resultant production of atmospheric turbulence. This could be achieved by tapping sources of heat which presently exist or perhaps by chemical means. These methods may be classified according to the source of heat: solar radiation, warm inversion layer, latent heat of vaporization, and chemical energy.

Solar energy is obviously the most extensive source if it can be tapped for the desired purpose, that is, raising the air temperature within a parcel of fog-laden air. Because of the obscuring and absorptive nature of fog, however, there is a minimum of solar radiation available at the earth's surface beneath a fog layer when it is needed for fog dispersal. Thus, its energy must be extracted at another time or place. One approach is to absorb the solar radiation when available and store it for future need. This method, reported by Junge (1958), required that the airport and the surrounding area be a vast radiator of stored solar energy. On the basis of the heat requirements discussed for direct application methods, such a scheme appears impractical. It is conceivable that if sufficient real estate were available immediately adjacent to the airport, the method might be applied to prevent or retard the formation of radiation fog. It would not, in any case, be a practical solution for the dispersal of coastal advection fog, which may be hundreds of meters thick upon arrival over the coastline and which continues to move ashore under the influence of the wind.

Solar energy is also suggested as a source by proponents of carbon seeding. This method involves seeding the top of the fog layer with carbon black or anthracite coal particles (Jiusto et al., 1967). It has been suggested that benefits might be realized in two ways. First, as a result of increased solar radiation absorption, droplets which capture carbon particles would evaporate and recondense on neighboring, non-capturing droplets whose temperature remains unchanged. Second, as a result of the carbon's absorptivity, the temperature of the entire air layer in which the carbon lies would be increased and the inversion thereby lowered. This hypothesis was tested in the laboratory by Van Straten et al. (1958) with inconclusive results. Later experiments with cumulus clouds demonstrated the effectiveness of carbon black as a dissipative agent. Clouds were also created from clear moist air by this means. It was later shown analytically by Fenn and Oser (1962) that the evaporation-condensation process is not operable in the carbon-seeded clouds because of heat budget considerations and that it is possible only to heat the layer by this method. Further, it was shown that dissipation by carbon seeding would require a minimum of 40 kg km^{-2} of finely milled particles ($r = 0.05$ microns) when the sun is near its zenith. Jiusto et al. (1967) later checked the calculations experimentally with inconclusive results. Some temperature increase was noted but no visible dissipation of the fog layer occurred. It was concluded that the method should be investigated further on cirrus clouds where the temperature increase would be greater by a factor of three and the effects of that change would be more apparent. If the method is practical at all, it has serious drawbacks. The delay time for a detectable response would be greater than for any of the other methods. Further, it could only be employed near mid-day because of zenith angle restriction; therefore, its utility would be limited to the most persistent fogs. It seems unlikely, therefore, that either of these methods of tapping the solar energy for fog dispersal is feasible.

The warm, dry air above the overlying inversion has been proposed from time to time as a likely heat source for fog dispersal. A few attempts have been made to tap this source. As noted earlier, Hagen (1961) failed to produce any discernible effect by means of an ionic current originating above an inversion. Diesel Power, Inc. built large fans whose purpose it was to produce a vertical exchange of air. These fans are reported (Junge, 1958) to have achieved some success in small localized areas. It is expected that under optimum conditions, a thin layer of radiation fog under a strong inversion, the system might be applicable but it is not feasible for use against thick advection fogs.

Another, and more provocative, idea for inducing a downward flow of air was tested by Magano et al. (1963). This method was based upon the use of falling water drops to set up a downward motion of the warm dry air, presumably by entrainment. It is not likely that this method would prove beneficial for all warm fogs, but in advection fogs of no more than a hundred meters thick, with an unstable layer near the surface, dissipative effects were produced. Essentially, the method involved only the release of water, at ambient temperature, from a hose opening of 3-cm diameter. The feed rate was 7 liters sec^{-1} at a helicopter flight speed of 60 knots, 100 m above the fog deck. A path 20 m wide was covered with drops of radius $r \leq 3$ mm, (eighty-seven percent were 1 mm or less) equivalent to a rainfall of 1 mm hr^{-1}. It is not known to what extent adiabatic heating of the descending air was a factor. In this regard, it should be noted that Hagen, in his experiment, forfeited the possible bonus value of adiabatic heating by working so closely to the surface that it could not be a factor of significance. The work of Magano et al. (1963) is significantly different in approach, in that it allows one more physical principle to become operative. On the other hand, one of the conditions under which the method was demonstrated is very restrictive, namely, the unstable layer near the surface. This would rule out its applicability in many cases, including radiation fogs. Since few refinements were utilized in these successful demonstrations, the question of the precise knowledge of fog parameters generally assumed prerequisite to fog modification is raised. Specifically, could the results be produced over a wider range of conditions and could the experimenters have been mistaken as to the causal factor in the tests? In this regard it was pointed out by Plank (1964) that the effect of the helicopter downwash was not eliminated from the variables. This was unfortunate because that effect is the basis, in its own right, of another approach to the problem.

The Air Force successfully tested the helicopter's downwash as a dissipative mechanism at Thule Air Base in Greenland. Hicks (1965) reported that an H-34 helicopter was used in a series of tests to drive the inversion air downward through the warm fog. In each case, clearing was produced over a path 75 m wide along the wake of the helicopter flight. It was predicted that a 1.6 km lane could be cleared in this manner in 10 - 15 minutes, in light wind. It is noted however, that because of filling, the lane could probably not be maintained in excess of this distance. Because of near-hover flight speed at only a few meters above the fog top, the Air Force method was considered unsafe and, therefore, suitable for emergency use only. Despite this, both the Air Force method and the Magano method warrant further study. The combined effects of the two appear very promising for small localized applications and could be suitable for larger scale use as well, under proper conditions. This is especially true in the case of light wind when the sun is near its zenith and there is no overlying cloud layer to interfere with the insolation process in the cleared region.

In addition to the above indirect methods, others are the introduction of large quantities of hygroscopic materials in a particular spot to essentially dry up that portion of the air parcel and raise its temperature by the release of latent heat of vaporization (Woodcock and Spencer, 1967). This air might then mix with the remainder of the air and produce the desired evaporation. Unfortunately, it would also produce an increase in the condensation nuclei population which might complicate the problem further by decreasing the visibility and by stabilizing the fog as it reforms. This method has apparently not been seriously considered in relation to fog dispersal but is extrapolated from experiments on the creation and modification of cumulus clouds.

Another method involving latent heat is that of refrigeration plus feedback (Wayne and Bell, 1953). The principle involved is that of condensing out much of the vapor water content by cooling the air. The latent heat of vaporization thus released would be used to heat the surrounding air. Heat would then be added to the cooled air as necessary to produce a very low relative humidity. If the process were practical, then only a fraction of the total parcel would require processing because each quantity of air so treated would sufficiently dry several times its own volume, thus permitting the desired evaporation to occur. No published results of such an experiment have been located, but it is believed to be impractical for other than a very small volume of air as in a laboratory experiment.

Chemical reaction is yet another possibility of an indirect heat source. Houghton and Radford (1938) suggested that a calcium oxide (CaO) reaction with carbon dioxide (CO_2) would release sufficient energy in the form of heat to satisfactorily evaporate most fogs, although it would thoroughly deplete the local carbon dioxide content of the atmosphere. Other proposals for chemical reactions have been made, but such methods give rise to many implications outside the realm of fog dispersal. This may account for the fact that apparently none have been considered seriously.

Of the heat methods of producing evaporation, only three hold any real promise for future study and application: FIDO, turbojet engine heating, and warm air downdraft. FIDO is essentially an operationally ready system, requiring only engineering developments to improve its efficiency. It would seem to be economically feasible in its present form in many locations, especially if it were made a part of the initial construction of a new facility. On the other hand, if turbojets can be shown effective under most conditions, it would be more economical, more flexible, and the preferred method for existing facilities.

b. Dessication Methods

Along with the heat methods, hygroscopic materials have been a very popular area of study. The reason is apparently that both of these general methods have been demonstrated under certain conditions. Houghton and Radford (1938) concluded that the use of dessicants to absorb moisture from the air was the most fruitful avenue of research. Consequently, they carefully planned and executed field tests of a method employing a saturated calcium chloride solution. Until very recently, the use of dessicants as dispersal agents was no farther advanced than when they published their findings. It now appears that some real progress has been made as will be discussed shortly.

Dessication is the process of drying, and for the present purpose, any number of agents can be used to dry the air. Among these dessicants, or hygroscopic materials, are silica gel, several strong alkalies, and some salts. In use, dispersed particles become condensation nuclei, absorbing water vapor. When sufficiently large, the droplets precipitate and may in addition, sweep out fog water droplets in their paths. Similarly, if the dessicant particles are in an air parcel before the humidity rises, they tend to prevent an increase in the relative humidity (Jiusto and Pilié, 1958; Pilié and Kochmond, 1967; Kochmond and Jiusto, 1968) above some threshhold value which is dependent upon the nature of the material used.

The two most widely studied hygroscopic materials are calcium chloride ($CaCl_2$) and sodium chloride (NaCl). These are both cheap and readily available. Houghton and Radford (1938) chose the former because it is also less corrosive than others. Nevertheless, corrosion is one of the serious drawbacks to the use of hygroscopic materials and any fog dispersal method for use around an airport with its variety of sophisticated and sensitive equipment must take this factor into account.

There have been only five techniques used for the application of this concept. Houghton and Radford did pioneer work with two of these: spraying a solution into the air from a ground installation and intensive drying of a portion of the air by means of anhydrous crystals. The third technique was used by the Cleaver-Brooks method ("No Fog" Dispersal Equipment, 1947) and involves the vaporization of $CaCl_2$ crystals in burners and, subsequently, discharge into the air parcel. Application of a liquid spray by means of aircraft in or above the fog is only a slight modification of the first technique. More recently, two additional methods have been attempted. The first is the use of a solution as before, except that the sprayed droplets are ionized upon discharge into the air by the nozzle (Beckwith and Flynn, 1968). The second is the distribution of dry particles of the hygroscopic material aloft, either by aircraft or by a large vertical fan on the ground (Coons, 1968a). The latter general technique led to some very promising experiments involving a relatively new concept, fog prevention. This will be discussed in the next section.

As Houghton and Radford (1938) viewed the problem, it was necessary to reduce the relative humidity to 90 percent in order to clear the air of fog. Their requirements for a satisfactory job was to produce and maintain a clear tunnel 40 m wide by 10 m in height. At the assumed wind speed of 5 m sec^{-1}, this clearing required a capability of clearing a volume of air at the rate of 2000 m^3 sec^{-1}. Using a horizontal pipe installation, 10 m above the surface, equipped with special nozzles along the pipe, it was found in eight tests over a two-year period that the desired effect could be obtained by the use of 5 liters sec^{-1} of saturated $CaCl_2$ solution in winds to 7 m sec^{-1} and at temperatures in the range 4 - 20C. They found, as others since have confirmed, that the size of the spray droplets is critical. If too large, the droplets fell out too quickly and did not achieve the desired effect; if too small, they failed to grow sufficiently large to fall out before becoming so dilute that the hygroscopicity was neutralized. In the latter case, additional droplets were thus introduced into the fog, the opposite of the desired effect, and visibility was, therefore, actually made worse.

In the final stages of their testing, Houghton and Radford (1938) designed a device for treating only a portion of the air. By blowing the air through a tunnel-like unit and exposing it to dry $CaCl_2$ particles, the relative humidity of the air so treated was reduced to fifty percent. Thus, by treating a fifth of the total volume of air, the relative humidity after subsequent mixing was the desired 90 percent. It was calculated that the amount of $CaCl_2$ required for this method was comparable to that required by the liquid spray technique.

More recent workers in the field are generally agreed that it is unnecessary to reduce the relative humidity as much as ten percent to accomplish the desired improvement in visibility. Jiusto (1967) and Jiusto, Pilié, and Kochmond (1968) demonstrated that the visibility could be improved significantly by a reduction of only one percent in a previously saturated air parcel. Since the smaller droplets evaporate first, the droplet-size spectrum is thus shifted toward the larger size with a small reduction in the liquid water content. Furthermore, it was shown that the reduction of the relative humidity by another one percent would require three times as much salt as the initial reduction. Consequently, their estimate of the amount of salt necessary to improve the visibility in the same volume of air as that of Houghton and Radford (1938) was less by two orders of magnitude. It must be noted, however, that these calculations have not been fully confirmed by field tests. Since their evaluations were based upon experiments in the 600 m^3 fog chamber of Cornell Aeronautical Laboratory, Inc., it has been believed by the author that field tests would show their estimate to be low and possibly inadequate due to diffusion and turbulent mixing (more effective in the higher humidity). Very recent tests conducted by personnel of Cornell Aeronautical Laboratory, Inc. (1969) at the Chemung County Airport near Elmira, N. Y., substantiate the laboratory tests. Since the details are unknown, no conclusions can be reached concerning the amount of NaCl required per unit volume.

In an experiment conducted by Isono et al. (1956) a saturated sodium chloride solution was sprayed into a fog at 1800 meters elevation on a mountainside. It was found that the sprayed droplets grew and fell out rapidly and, according to their calculations, the stratus cloud had lost 88 percent of its liquid water content within two minutes after the salt solution seeding. In the process, the droplet-size spectrum was shifted toward the larger sizes, confirming the theory of dessication. It should be noted that these findings were somewhat qualitative in nature and did not establish any parameters quantitatively.

In a series of tests for United Air Lines reported by Harrison (1952) a "secret" chemical was used to dissipate the fog. The solution was discharged by nozzle into the plane's exhaust stack and vaporized. During the earlier period of testing, the results were very impressive but, during the latter period, were very disappointing. Because of the secret nature of the chemical, nothing can be learned from these results. It has since been reported by Beckwith and Flynn (1968) that the chemical used in the above tests was salt brine. The cause of the inconsistent results remains unknown although the contractors, Brandau and Kooser, believed it to stem from the use of a different spray aircraft during the later period (Harrison, 1952). One member of the above contracting firm recently tested, among other substances, ionized salt brine (Beckwith and Flynn, 1968). The results were said to be impressive; however, because more than one substance was used in the various tests, it is not known which of them were actually responsible for successes produced. Furthermore, since the information is proprietary in nature, detailed reports are not available for study.

The previously mentioned Cleaver-Brooks method of producing a vapor from $CaCl_2$ crystals was presumable a failure. The first attempt using crude burners was unsuccessful and since nothing appears in the literature, it is assumed that the proposed installation ("No Fog" Dispersal Equipment, 1947) of four improved burners at the Lockheed air facility was also a failure, if actually installed. A modified device was briefly tested at the Landing Aids Experiment Station, Arcata, California (Macdonald, 1949a, b). This device produced water vapor in a boiler and an aqueous solution of $CaCl_2$ was injected into this vapor and mixed. The mixture was discharged as a visible fog of $CaCl_2$ droplets in water vapor. In the very brief tests, no discernible improvement in the natural fog visibility was detected. It was noted, however, that test personnel readily felt the effects of the salt on their skin. A deposit of $CaCl_2$ was also noted on the ground after each of the tests. Testing of this device was discontinued and the method has apparently been abandoned.

Other materials have been either tested or suggested but results are unknown. Among these are ammonium nitrate, urea, gypsum, potash, some phosphates, and fertilizer. Investigation in this area is in its infancy and should be encouraged. On a small scale, considerable research could be accomplished with the aid of a vertical air fan such as that used by the Air Force in Project Cold Fan. This device has been demonstrated and is capable of lifting particles of dry material less than 50 microns in diameter, specific gravity of 2.5 or less, to heights of 38 m or more in light winds (Coons, 1968a). In a suitable location, successful dispersal of fog might well be achieved with equipment of considerable less power. An example of such an environment is a gently rising ridge or a knoll over which a light to moderate wind advects the fog. Thus, large and sophisticated wind machines such as that used by Kochmond and Pilié (1969) are not absolutely necessary.

C. RETARDATION OF FOG FORMATION

A recent conceptual development in fog modification is that of pre-seeding an air parcel to prevent or retard the actual formation of fog. Kochmond and Jiusto (1968) demonstrated the pre-seeding effects of sodium chloride. Particles of NaCl between one and five microns in diameter were introduced into a 600 m^3 fog chamber. Humid air was then drawn into the chamber from the outdoor environment, allowed to reach equilibrium, and expanded adiabatically. Initially, the salt particle concentration was 10 cm^{-3}. After four minutes, the concentration was 8 cm^{-3} as compared to 350 cm^{-3} in the control fog after the same time lapse. The extinction coefficient in the seeded fog at that point was a quarter of that in the control fog for unit mass of liquid water content. As the expansion continued, the liquid water content of the pre-seeded fog became much greater than that of the control fog; yet the visibility remained better. With time, conditions in the seeded fog approached those in the control fog but only after dilution had counteracted the hygroscopic effects of the salt particles. Thus, the validity of the concept was established.

Another study of fog suppression followed from the work of Jiusto (1964) dealing with the use of a long-chain alcohol mixture of hexadecanol and octadencanol. On the hypothesis that particle growth could be retarded by the use of this surfactant, experiments were conducted by Bigg, Brownscombe, and Thompson (1969). The substance, dispensed in the form of a vapor by a propane smoke generator, was assumed to have condensed on atmospheric nuclei, forming a monomolecular layer. In four tests on nights when radiation fog was expected, fog formation was apparently prevented, since it did occur all around the test site. Although the method appears successfully demonstrated, the investigators cautiously noted that some aspects of the tests were not completely convincing and they chose to state only that observed results were consistent with their having modified the formation of the fog.

Both of these methods for inhibiting the formation of fog are applicable only to radiation fog. The concept is not extendable to advection fogs since they are advected into a region in a fully developed form, and the same wind which brings in the fog would remove the particles previously coated or introduced for modification purposes. The methods should be pursued further, however, because of their potential value in certain regions of the United States.

D. SUGGESTIONS FOR FUTURE RESEARCH

The state of the art with respect to artificial dispersal of fog is such that no avenue offering a glimmer of possibility should go unexplored with the exception of those methods which have repeatedly failed or are basically unsound. This includes those methods based upon the application of an electric field, a sound field, any form of radiant heat or sensible heat exchanger, the physical replacement of foggy air, and entrapment by a large fixed obstacle or network of obstacles.

With respect to presently known methods, large scale testing should be done with jet engines, dessicants, surfactants and methods of tapping the heat source above the inversion.

Exploratory work on a lesser scale should be conducted to check the conclusions of Buxton et al. (1968) regarding the use of sprayed seawater. Although their study considers an impractical solution for its intended purpose, it would be ideally suited for harbor use and for underway replenishment, if the spray vessels are available when needed. It is conceivable that an adaptation of this system might be appropriate for permanent installation on certain classes of ships. It is possible that such an adaptation might prove to be excellent in combination with the CVA - jet engine system of Todd and Nickerson (1968).

Although the best weapon of the aircraft carrier against fog is its mobility, the ship's configuration invites conjectures regarding possible solutions. The seawater system adapted to fantail mounting is one such suggestion. Another is the incorporation of powder dispersing equipment in the ship's exhaust stack by means of which hygroscopic particles could be dispensed into the fog.

The knowledge gained from recent experiments in retarding the formation of fog should be applied to a study of the feasibility of applying them at the source of advection type fogs. Such a study must consider not only the possibility and practicality, but also the long-range effects of such action on the heat and water budgets and the natural environment in both the source region and the downwind coastal region.

III. LOCAL INVESTIGATION OF WARM FOG CHARACTERISTICS

Numerous investigators in the field of fog modification agree that successful modification of warm fog on a routine basis is not likely to become a reality until such time as the basic mechanisms involved are more clearly defined. This implies a lack of knowledge of the parameters involved and the degree to which they interact. As pointed out by Wayne and Bell (1953), fog is a dynamical phenomenon and exists in delicate balance within the atmosphere under the influence of local and synoptic scale influences.

In an effort to gain a better understanding of fog as it occurs on Monterey Peninsula, a study was made of the weather observations over a one year period, from 1 June 1968 to 31 May 1969, at the Naval Auxiliary Landing Field (NALF Monterey), Monterey, California. In addition, an attempt was made to determine some of the physical characteristics of the fog at that and other locations on the Monterey Peninsula.

A. STUDY OF LOCALLY OCCURRING FOG AT NALF MONTEREY

The search for a better insight into the mechanisms involved in the occurrence of fog for application to the study of fog dispersal showed a need for accurate and complete data for a period of time at some fixed location. Since it was desired to study the fog on the Monterey Peninsula, the only records available were those at the Naval Weather Service Environmental Detachment (NWSED) at NALF Monterey. This unit is the source of weather observations reported by the Monterey Peninsula Airport, located at the same field (Fig. 4). Weather observations are made with the aid of standard meteorological instruments and qualified

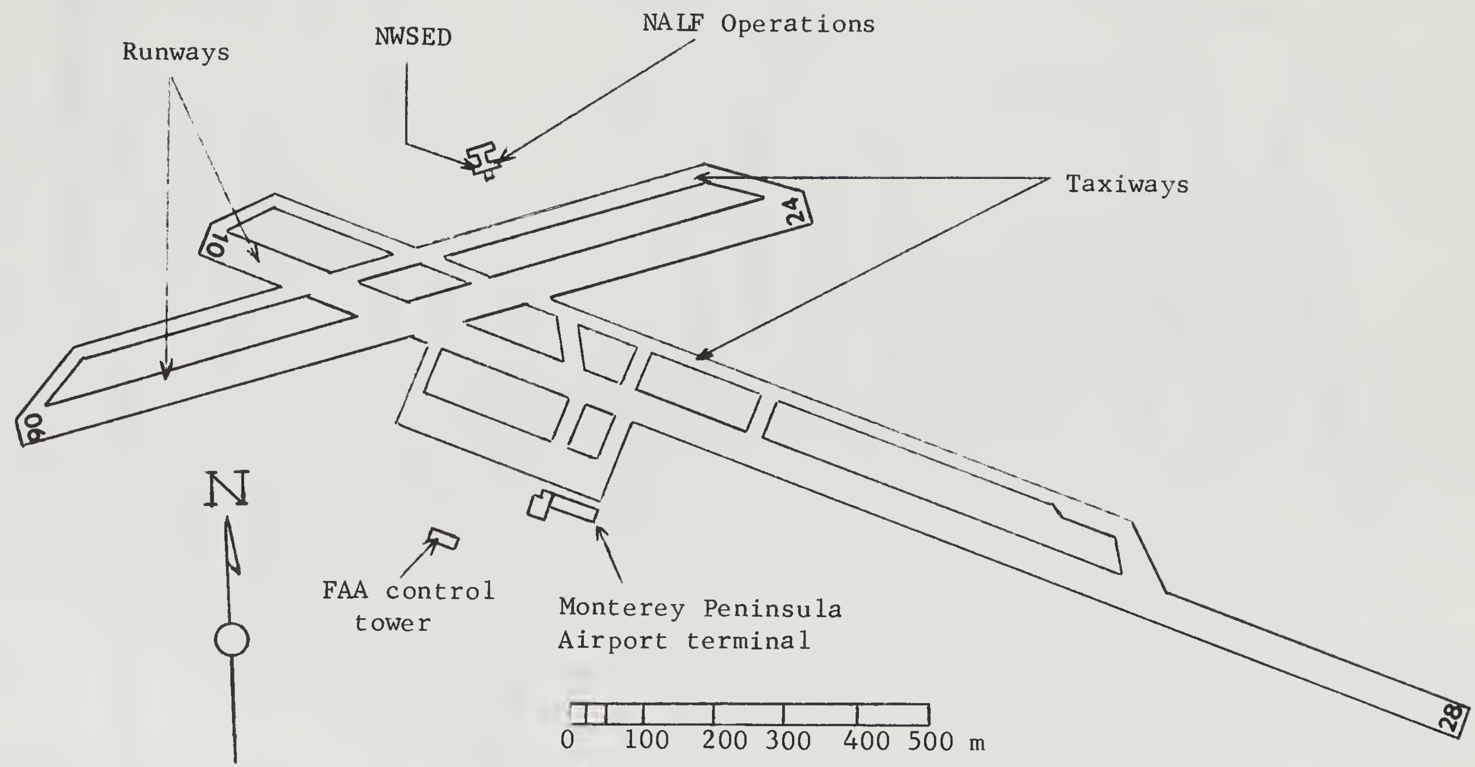


Fig. 4. Orientation of Runways at the Naval Auxiliary Landing Field and the Monterey Peninsula Airport, Monterey, California.

personnel. Fig. 5 shows the location and orientation of various instruments at the field. Important instruments for the purpose of this study were the AN/GMQ-10C Transmissometer Set and the AN/GMQ-13 Cloud Height Set. Both of these sets are of the continuous recording type and provide a valuable record of ceiling and visibility.

Although the data from NALF Monterey represents the best available on the peninsula, it is not perfect. One important fact is that the meteorological unit is not manned from 2200 to 0500 PST. Hence, observations made by FAA tower personnel for the hours 2300 to 0400 PST are used to fill the blanks in the case of ceilings, weather, visibility and winds. It has been determined that this is more practical than obtaining them from the instrument tracings. A comprehensive study should, of course, encompass those recordings rather than the tower observations because of greater consistency with the primary observations. For the purpose of this study, the tower data are deemed adequate for continuity.

1. Topography of Monterey Peninsula

Monterey Peninsula is the seaward extension of the Santa Lucia Mountain Range which lies to the southeast. It is also the southern headland of Monterey Bay. Physically, the Santa Lucia Range is a ridge across the central peninsula and, as such, separates the slope to Monterey Bay to the north from the steeper slope to Carmel Bay to the south.

The Naval Auxiliary Landing Field is located at 36^{o} 35' north latitude and 121^{o} 51' west longitude 2.4 km from Monterey Bay. Situated on a gently rising slope, the field has a mean elevation of 49.5 m. The ridge from the west around to the southeast lies at a distance of 1.5 - 5.0 km from the field and has a mean elevation of 180 - 275 m (Fig. 6).

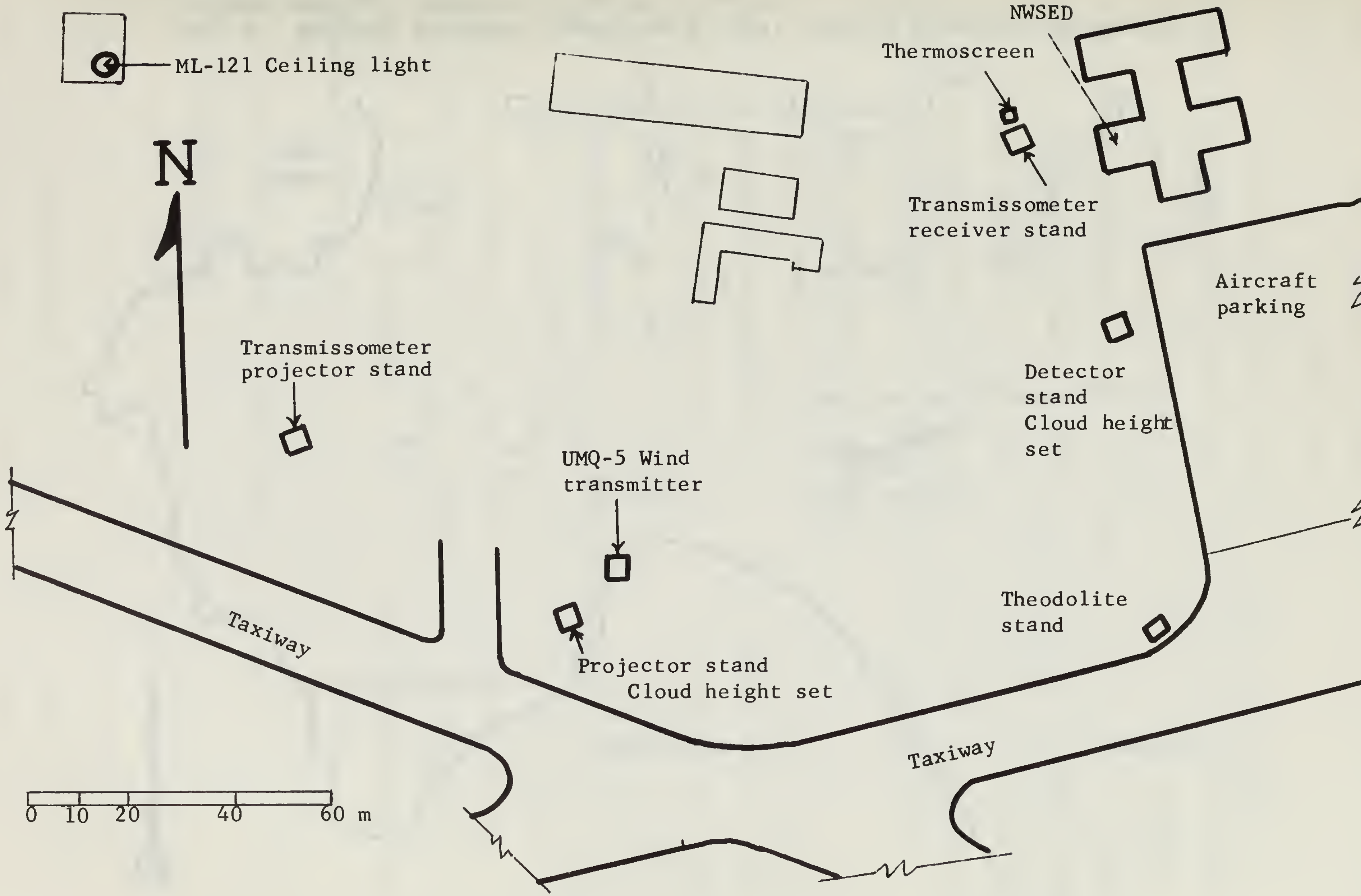


Fig. 5. Meteorological Instrument Location at NALF Monterey, California.

Fig. 6. Monterey Peninsula showing major local features affecting the weather at NALF Monterey. Elevation is given in meters.

Thus, the field is naturally protected from the majority of the advective sea fog moving up the California coast.

The Salinas Valley lies between the Santa Lucia Range to the west and the Diablo Range to the east. Although not a part of the Monterey Peninsula, this valley has a profound effect upon NALF Monterey under certain conditions. Moist maritime air from the valley entrance on Monterey Bay is carried far inland by a valley breeze. Nocturnal cooling then produces frequent radiation fogs. It is believed that the relatively high frequency of fog at NALF Monterey during easterly winds is caused by advection of radiation fog through a gap from the Salinas Valley.

2. Period of Observational Data Study

The period of study was chosen to coincide as nearly as practicable with the period of the grant from the Naval Weapons Center, China Lake, California, fiscal year 1969. Because of the time element involved in thesis preparation, it was decided to slide the 12-month period one month to include June 1968 and terminate with May 1969.

Figs. 7 - 10 show the occurrence of below-minimum conditions by month over a 13-month period. June 1969 is included here for informational purposes and involves only one observation of below-minimum conditions. It is not included in Figs. 11 - 13 which are based upon observations for the stated 12-month period.

B. FOG STATISTICS DURING THE STUDY PERIOD

1. Scope of Study

Under the guideline dictated by the international definition of fog, only that fog in which the visibility was reported as one kilometer or less was considered of interest. Further, since this study was aimed at fog dispersal as applicable to air operations, only

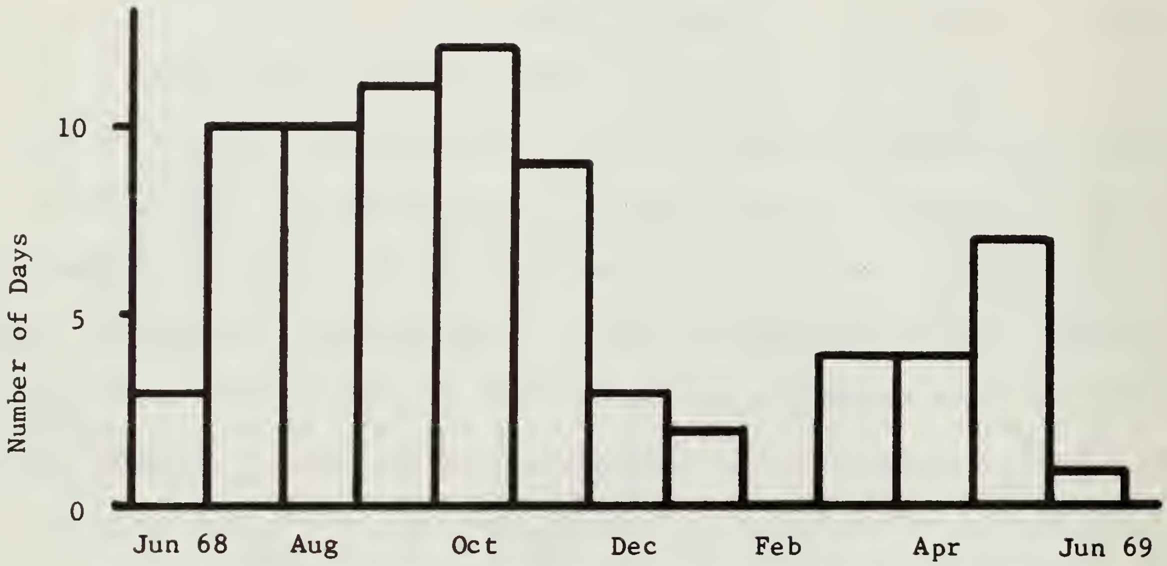


Fig. 7. Number of days per month during which below-minimum conditions existed at the time of one or more record observations.

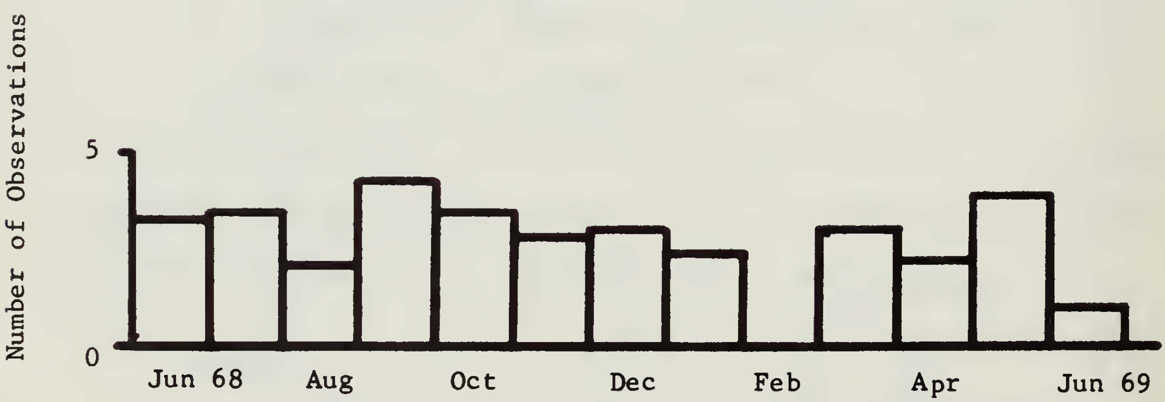


Fig. 8. Average number of below-minimum observations per below-minimum day. (The above and subsequent figures are based upon observations at NALF Monterey during the period 1 June 1968 through 30 June 1969.)

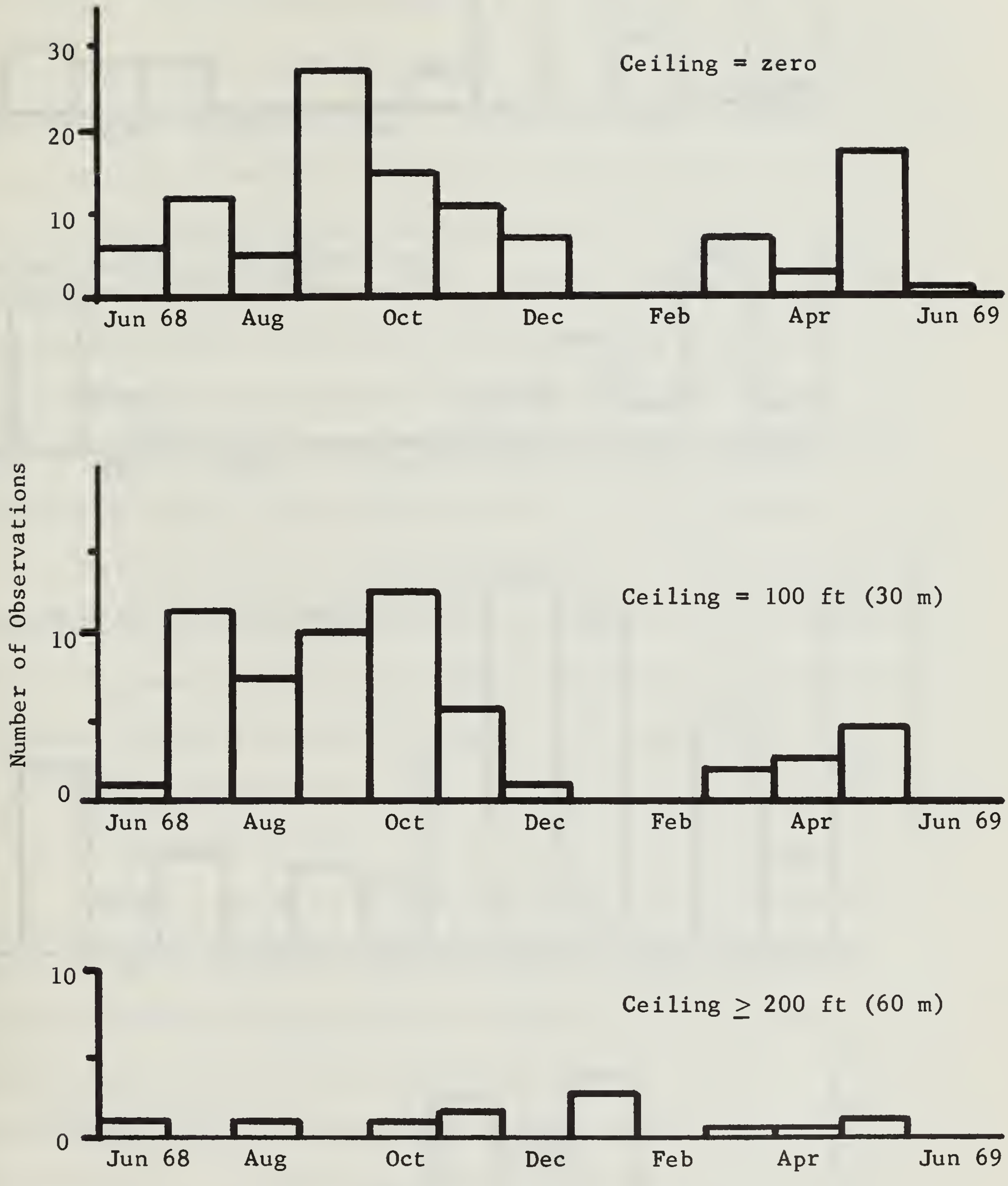


Fig. 9. Monthly occurrence of ceilings of 0 m, 30 m, and 60 m or greater during below-minimum conditions.

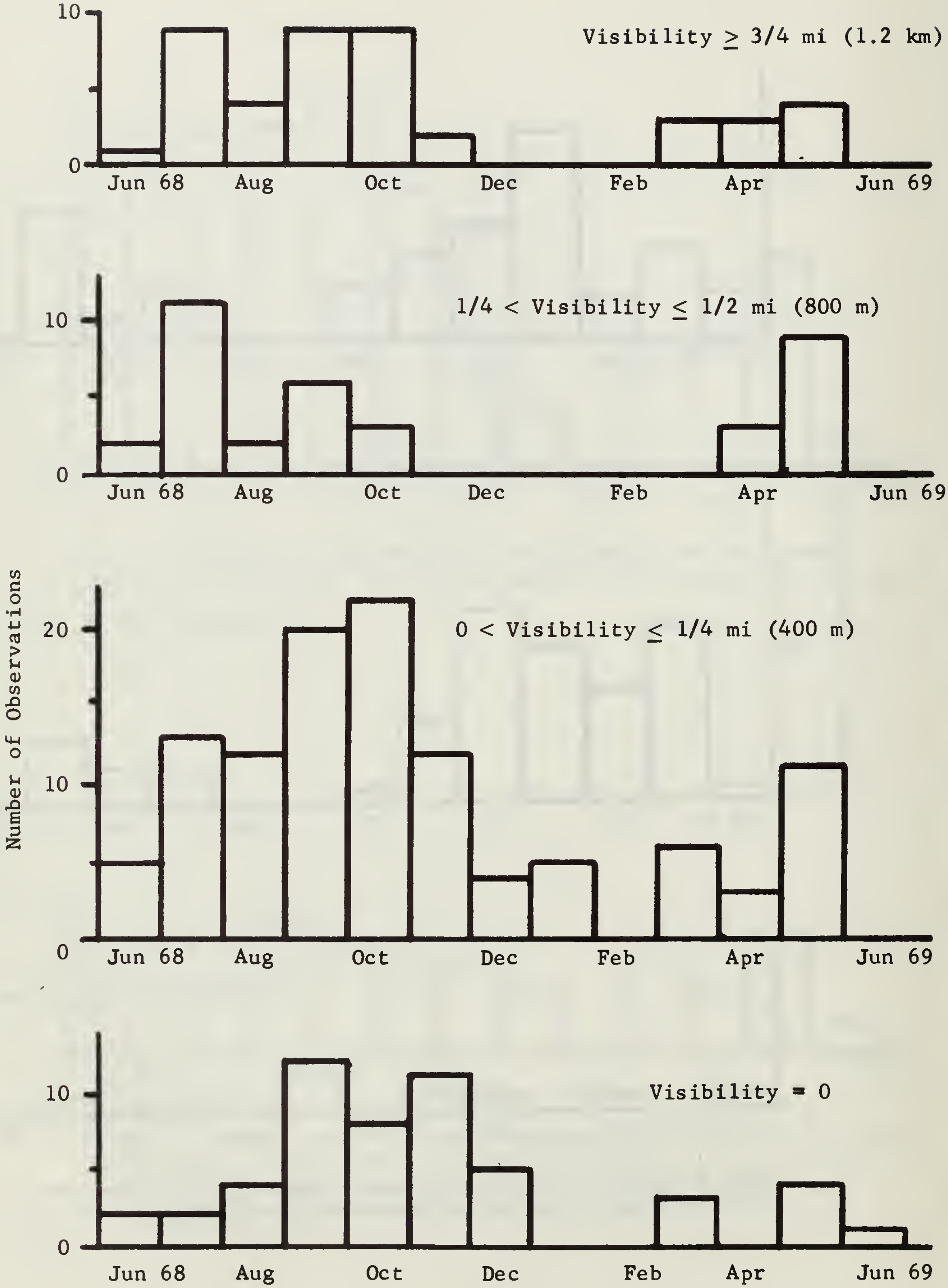


Fig. 10. Monthly occurrence of visibilities of 0 m, to 400 m, to 800 m, and 1.2 km and greater during below-minimum conditions.

those cases were considered in which the ceiling or vertical visibility was reported less than 200 ft (60 m).

Subsequently, it was determined that for the sake of consistency, only cases in which the field would be closed should be included in the study. This meant that some visibilities greater than one kilometer were included because the ceilings were less than 60 m and, conversely, some ceilings of 60 m or greater were included because the visibilities were less than 800 m. It should be noted that this represents a further restriction on the international definition and eliminated fog cases in which the visibility was in the range of 800 - 1000 m. However, this adjustment resulted in the elimination of only 15 observations.

The total number of observations remaining in the study was 244 spread over a total of 75 days. These were analyzed for variation as a function of season, time of day, ceiling, visibility, wind speed and direction, and relative humidity.

2. Results of Data Study

a. Seasonal Variation

Fig. 7 shows the seasonal dependence of fog occurrence at NALF. The months of July through November 1968 showed the highest frequency of fog and accounted for 171 observations (70 percent) over 52 days of incidence (69.4 percent). Fig. 8 shows the relatively constant average number of observations of below-minimum conditions per below-minimum day. It should be noted that except for February (no below-minimum days) and June 1969 (which is included only as further evidence of the variability of fog) the average is very near to three observations per day over the 12-month period.

It should also be noted that the most frequent occurrence of below-minimum conditions is coincident with the local "summer" in September, October, and November. This indicates that fog is more prevalent although the coastal fog and stratus is less frequent. Hence, one is led to the conclusion that in these months the local fog is primarily radiative in nature rather than advective.

It is difficult to draw conclusions about the seasonal variation of below-minimum conditions and their dependence on synoptic scale features. The coastal stratus is very much in evidence near the airport. It can be seen hugging the coastline almost daily on the summer and fall satellite pictures. Just as frequently, orographic stratus is observed topping the peninsular ridge under the influence of winds from the southwest quadrant. This phenomena is outside the scope of this investigation, however, because the field remains open for operation under either Visual or Instrument Flight Rules, relatively unhampered.

b. Diurnal Variation

Fig. 11 illustrates the extent to which below-minimum conditions occur during the night and early morning. The earliest occurrence appears at 1700 (all times PST) and the maximum frequency is reached at 0600. This is apparently the result of coastal fog and stratus clouds moving ashore following the afternoon temperature maximum. An examination of the variation of below-minimum conditions with respect to local winds presents another view of the diurnal variation.

c. Wind Dependency

Contrary to what one would expect in a region of frequent advection fog, the most severe cases do not occur during light onshore winds. The wind was calm in 47 percent of the actual cases of below-minimum conditions. Fig. 12 illustrates the decrease in frequency with increasing wind speed.

Although the wind is reported as calm in almost half the cases, it must be assumed that some movement exists, however small, to drive the fog inland. (In this respect it should be noted that wind less than two knots is normally reported as "calm"; therefore, the four observations of one knot in Fig. 12 are incorrect in this sense.) Once over the field, the fog may remain for some time before the land breeze increases sufficiently to move it seaward. In the absence of a land breeze, the fog will persist until burned off after sunrise. Observers and forecasters of the Naval Weather Service Environmental Detachment at NALF Monterey are generally agreed that radiation fog is a significant part of the problem during the months of September through November. This is evidenced by later occurrence and earlier burn-off. It is further believed by the author that this radiation fog is, in a large measure, advected from the Salinas Valley and, therefore, considerably different in nature from either local radiation fog or advective sea fog.

In an effort to isolate these radiation fogs, in support of the above, the data was evaluated by excluding September, October, and November observations. Fig. 13 illustrates the variation of below-minimum conditions as a function of wind direction. It is readily seen that during the months of peak incidence, the wind was somewhat more frequent from an easterly direction. This is borne out by climatology which indicates that although winds from this general direction are much more infrequent than the westerly winds, they are, on a percentage basis, more likely to be associated with very low ceilings and reduced visibility.

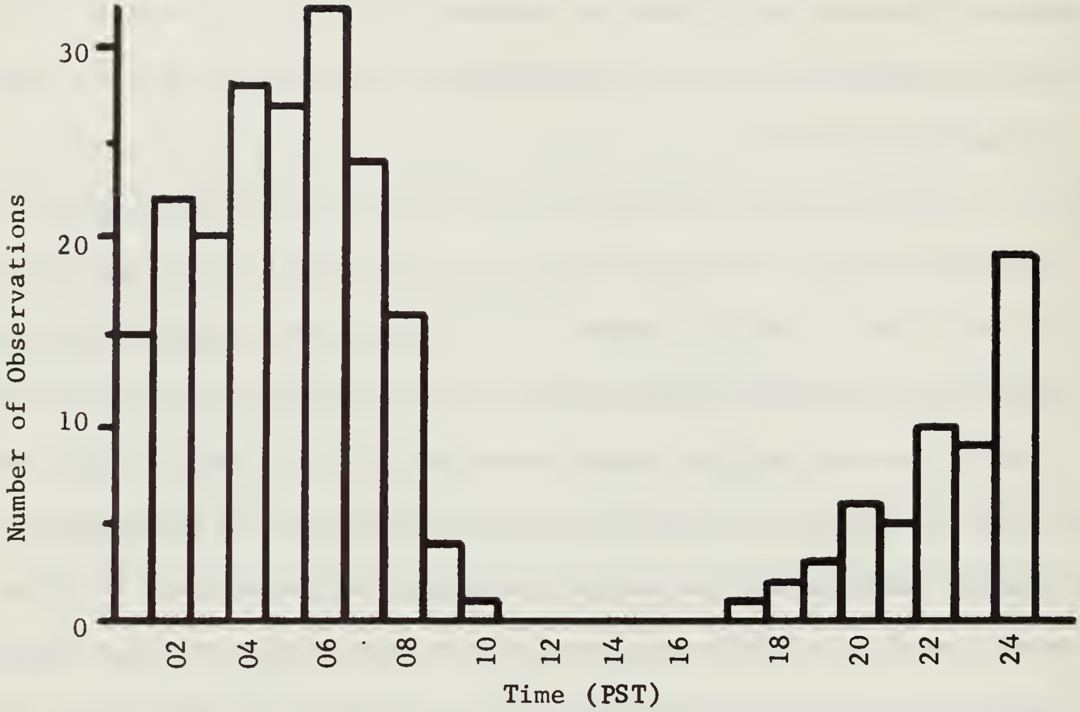


Fig. 11. Occurrence of below-minimum conditions as a function of time.

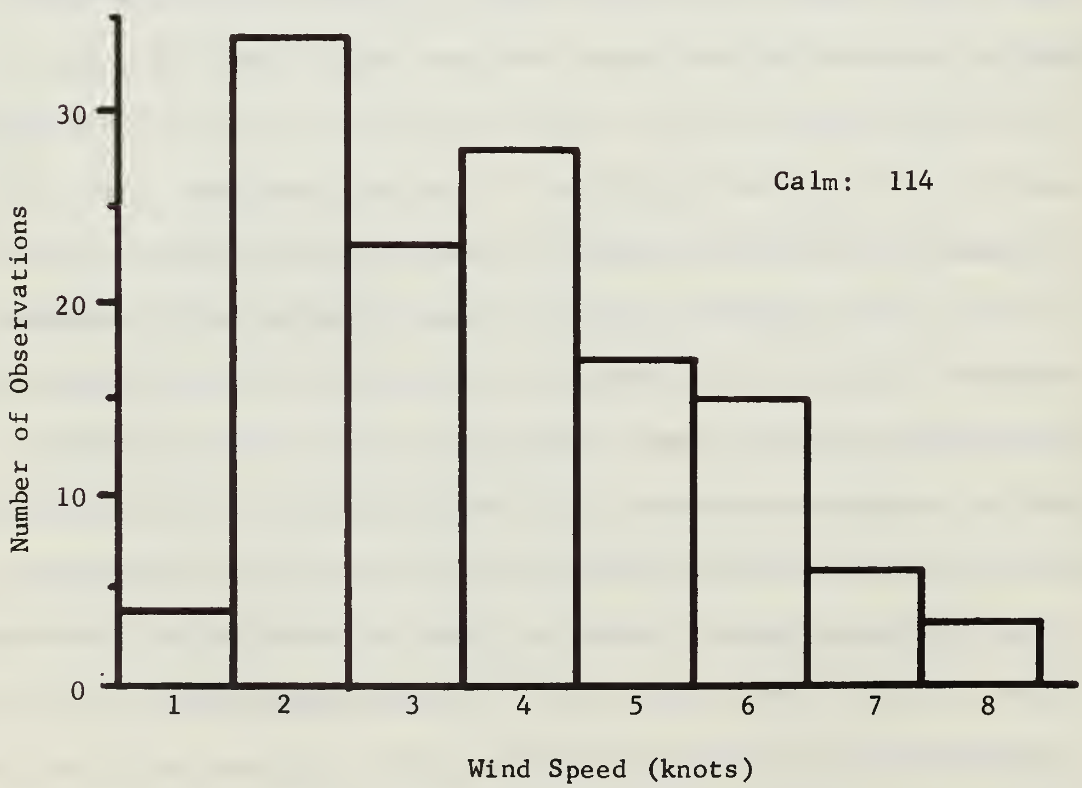


Fig. 12. Occurrence of below-minimum conditions as a function of wind speed.

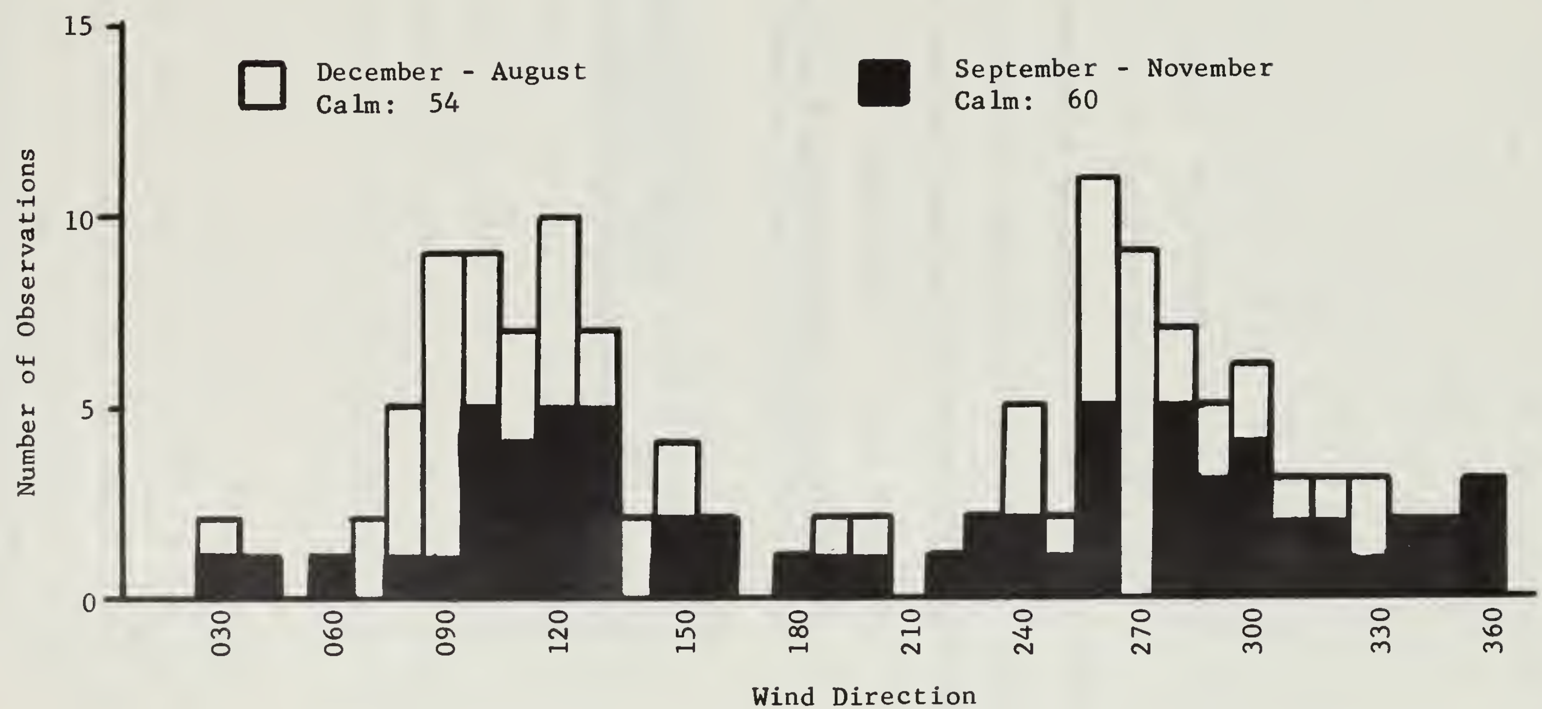


Fig. 13. Occurrence of below-minimum conditions as a function of wind direction. (This and subsequent summaries are based upon one year's record observations during the period 1 June 1968 through 31 May 1969.)

Thus, it is seen that the true advection fog is generally associated with westerly winds while those more radiative in nature appear to be associated more often with easterly winds.

d. Relative Humidity Relationship

It would be most presumptuous to reach any precise conclusions concerning relative humidity at the field due to the different types of fog involved and a large quantity of missing data. Table III summarizes the frequency of below-minimum conditions as related to relative humidity. As indicated earlier, the missing data represents those observations, which do not include relative humidity, obtained through FAA tower personnel. As before, the data have been evaluated with and without the months of September, October, and November.

TABLE III

Frequency of Below-Minimum Conditions as a Function of Relative Humidity

Relative Humidity (%)	Number of Observations Total	Number of Observations Less Sep, Oct, Nov
Missing	115	59
100	68	30
99	12	4
98	19	15
97	11	9
96	7	5
95	6	3
94	3	3
93	3	2

When the data are considered in the absence of those from September, October, and November, fewer relative humidities of 99 and 100 percent are noted than are expected. It should be noted that although about half the missing data occur in those three months, this is also approximately the same proportion of the total observations occurring in those months (47 percent). The only conclusion to be made from the relative humidity is that it tends to support the theory of predominantly radiative fog being associated with the easterly winds during the months of maximum fog frequency.

C. INVESTIGATION OF PHYSICAL CHARACTERISTICS

During the latter period of study of observational data, a number of experiments were conducted to determine certain physical characteristics of locally occurring fogs at NALF Monterey. Fewer samples were obtained than were desired because of nature's failure to cooperate during the allotted time.

1. Scope of the Investigation

The knowledge desired from the experiments was primarily the droplet-size distribution. From this the mean droplet radius could be determined. Based upon a knowledge of the wind and the visibility, the droplet concentration and the liquid water content could be determined. These parameters were to be used for comparison with the fog model previously discussed.

It was desired to sample as many fogs as possible in the period of study. During June and July, 1969, the expected fog frequency did not occur. During this time, only four fogs were sampled and these involved drizzle as well. Four random samples were also taken in stratus at other locations on the peninsula for comparative purposes.

2. Method of Approach

For the purpose of these experiments, an accurate measurement of visibility and wind speed was desired. It was intended to obtain samples of fog droplets. From these samples the droplet-size spectrum could be determined. Using exposure time during which the samples were taken and the wind speed, the droplet concentration could be determined. Using the mean droplet size and the visibility, the liquid water content of the fog could be computed using Eq. (1).

A minor objective in these experiments was to test a crude but very simple method of fog sampling. Such a method would be of great value for increasing present knowledge of fog characteristics. Sampling could be done on a wider scale without the usual large outlay of funds for instrumentation. Specifically, gelatin coated slides hand-held by weather observers, as a part of their usual routine, could hardly be more simple. Consequently this method was used.

Fog droplet samples were obtained through the use of gelatin-coated glass slides. The theory of this method of sampling, used by many investigators, is that the water content of each individual droplet is sufficient to dissolve the gelatin coating on the glass over a circular area whose radius is twice that of the water droplet (Jiusto, 1965, 1967). As the water evaporates, a crater is left in the gelatin coating. Microscopic study of the slide is then possible at a later time.

In addition to the measurements required above, other measurements were also needed to make the results more meaningful. These measurements were: a) wind direction which would aid the identification of the type fog involved and provide a clue as to possible natural modification since formation; b) ceiling or vertical visibility for classification and correlation to previous data; c) fog thickness (not locally available) to assist in identification; and d) wet and dry bulb temperatures which were required to determine relative humidity and further aid in the identification of the fog and its stage of modification.

Frequency of sampling is, of course, more meaningful in a dynamic situation if done continuously or at frequent intervals. However, since the samples were to be evaluated visually, a sample interval of one-half hour was decided upon as representing the best compromise. Exposure times would then coincide with the record observation and with a special observation on the half hour.

3. Instrumentation

Visibility was determined by the AN/GMQ-10C Transmissometer Set at NALF Monterey. This instrument has a 152.4 m baseline oriented NE - SW, essentially parallel to and at a distance of 210 m from runway 06 - 24. Fig. 5 shows the receiver stand, located near the thermoscreen. The transmissometer beam is projected across a wide ravine and is approximately 10 m above the ravine floor. (This produces discernible orographic effects when the wind is from the northwest quadrant.) The continuous recording device is located within the building housing the Environmental Detachment, 11 m to the east.

Ceiling height is determined by means of the AN/GMQ-13 Cloud Height Set. This instrument operates on a 121.9 m baseline parallel to that of the transmissometer. Vertical visibility in fog is normally determined visually and is therefore highly subjective.

Wind speed was determined by two methods, initially. The first of these was the AN/UMQ-5 Wind Recording Set. The detector for this set is located near the Cloud Height Projector in Fig. 5. The recording device is a component within the AN/GMQ-14B Semi-Automatic Weather Station, inside the meteorological spaces. A repeater is available with wind speed and direction dials so that the mean wind may be determined subjectively. Because making the observations is a one-man operation, however, speed and direction are normally picked off the inked tracing. The same procedure was used in this case because the method is consistent with the observational data previously studied. The second method used initially was the hand-held Anemometer-Wind Vane, ML-446/PMQ-3. It was intended that the hand-held anemometer, being at the sampling location, would produce more accurate measurements of the true wind at that spot. It was subsequently determined, however, that since a time averaging process over the sampling duration was required, the wind measurements obtained from the AN/UMQ-5 Wind Recorder were adequate.

The heart of the experimental work was obtaining the fog droplet samples. This was accomplished through the use of gelatin-coated standard glass specimen slides for microscope use. Such a technique has been widely used for this purpose. It was decided to use the gelatin mixture suggested by Jiusto (1967), 10 percent (by weight) gelatin powder (a commercial unsweetened product) and 90 percent hot distilled water. After the solution was thoroughly mixed, food coloring was added to produce additional contrast in the droplet craters.

While the mixture was still hot, it was spread in a thin coat over standard pre-cleaned glass slides with the aid of a plastic rod. The slides were then placed on a flat surface in a room which could be left uninhabited (to reduce the motion of dust particles) during the drying time of the gelatin coat. (A completely dust-free space, if available, is recommended for the drying process to reduce the clutter on the finished slide.) After the water was evaporated from the mixture, a very thin film of dry, colored gelatin remained. The slides were then replaced in the original container for later use.

In practice, the slides should be at ambient temperature and allowed to "set" for a few minutes after exposure at or near the ambient relative humidity. Both of the precautions are necessary to ensure the best possible resolution of the smaller droplets; otherwise, these droplets may well evaporate before their impressions have been formed in the gelatin coat. Similarly, it was found that the thinnest possible coat was desired for those smallest droplets. In earlier experiments with the slides, surface impressions only were obtained and these were extremely difficult to observe under the microscope.

During exposure to the fog droplets, the slides were held at arms length in the direction of the wind, 1.8 m above the ground. One slide was held perpendicular to the airflow and the other at a 45° angle to the axis of flow. The purpose of the two slides was to provide a check on airstream effects in the resultant distributions.

The duration of slide exposure to the foggy air was adjusted to the wind. The aim was to get a good distribution, representative of the air parcel without undue difficulty in counting and sizing an abundance of craters. In the very light winds usually found, an exposure time of one minute was used.

Slide exposure (in westerly winds) was made at the thermoscreen (Fig. 5) which is about two meters from the transmissometer receiver. After exposure, the slides were placed in a wood slide file, which had been previously opened to the atmosphere, and the cover was loosely positioned to allow proper drying.

Exposed slides were later examined with the aid of a Bausch and Lomb Dynazoom microscope with integrated 35 mm camera system. This instrument was equipped with a 3.5X, 10X, and 43X objective lenses and 10X eyepiece lenses, producing magnification of 35X, 100X, and 430X. The droplet craters were photographed on Kodak Panatomic-X film with the aid of an etched metric overlay which divided most of the slide into 2 mm squares. The entire slide was first examined visually for abnormal distribution, then five consecutive squares were photographed individually on each slide. The magnification of the image on the film plane, using the 3.5X objective lense was 7X. A microscope scale with divisions of 1.0, 0.1, and 0.01 mm was photographed in an identical manner.

Droplet sizing and counting was accomplished in the following manner. The negative of the metric scale was projected on a wall using a strip film projector. The position of the projector was adjusted carefully to produce a wall image of 1 mm equal to 0.01 mm on the original scale, or a total of 100X magnification. Graph paper with centimeter and millimeter divisions was then used to slide over the wall and permitted rapid and accurate sizing of the craters. Further, a page of computer output paper was taped to the wall. As the craters were sized, the crater diameter was jotted over the image for later tallying in 10 μ intervals. This procedure permitted a detailed examination of many more samples than could have been accomplished using the microscope alone.

4. Discussion of Results

The extent of the sampling performed is set forth in Table IV. It should be noted that the samples obtained at NALF Monterey on 30 June 1969 are not within the scope of this study and are included for comparison only.

TABLE IV

Fog and Stratus Sampled on Monterey Peninsula
During May - July 1969

Case	Date	Location	Total Samples	Sky Cover	Visibility (100 m)	Wind Speed (kt)
I	5-20-69	Ridge	4	W2X	12	5
II	5-21-69	NPS	2	W2X	8	3
III	6-2-69	NPS	2	WOX	2	4
IV	6-30-69	NALF	4	W2X	32	3-5
V	7-1-69	Ridge	2	W2X	8-16	6-8
VI	7-11-69	NALF	3	W1X	4-8	00
VII	7-30-69	NALF	6	W1X	2-8	1-4
VIII	7-31-69	NALF	8	WOX	1-3	1-4

Typical droplet-size distributions for the eight cases are shown in Figs. 14-21 with pertinent parameters indicated thereon. The concentration indicated has been normalized to the number impinging on 1 cm^2 sec^{-1} without regard to wind speed. It should be noted that the droplet concentration is extremely low as compared to the model and the studies of the literature. This is not surprising, however, since the samples were taken 1.6 m above the surface. Further, determination of visibility is a spatial integration process whereas the sampling location

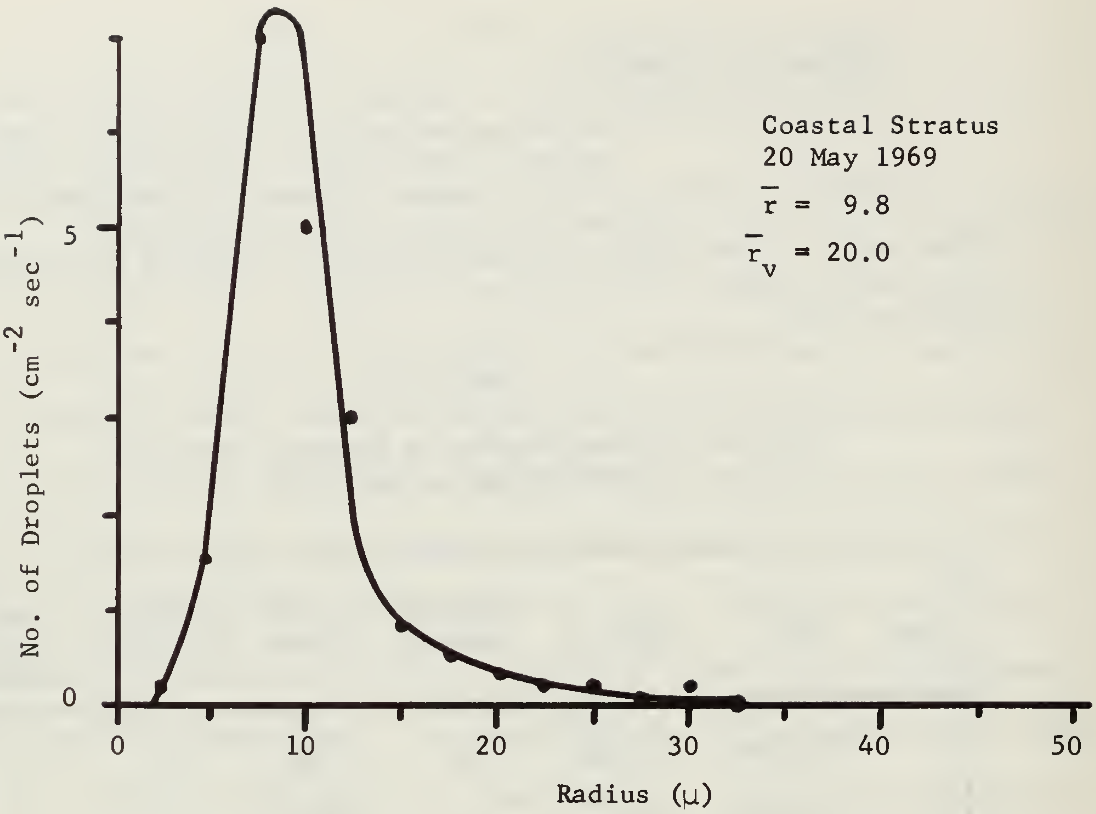


Fig. 14. Droplet-size spectrum in coastal stratus on the SE slope of the Santa Lucia Range.

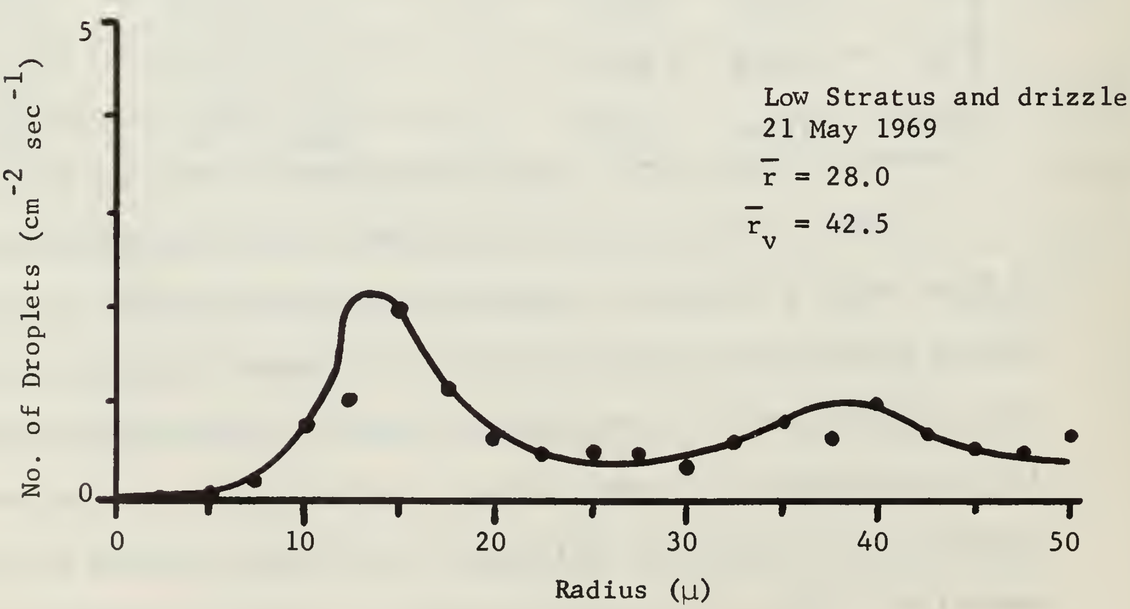


Fig. 15. Droplet-size spectrum in low stratus atop Spanagel Hall at NPS, Monterey, California.

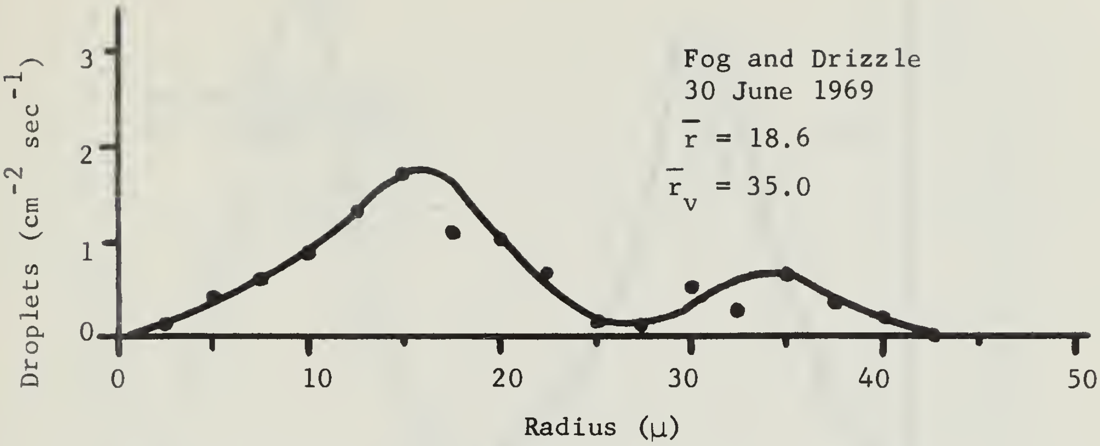


Fig. 16. Droplet-size spectrum in fog and drizzle at NALF Monterey.

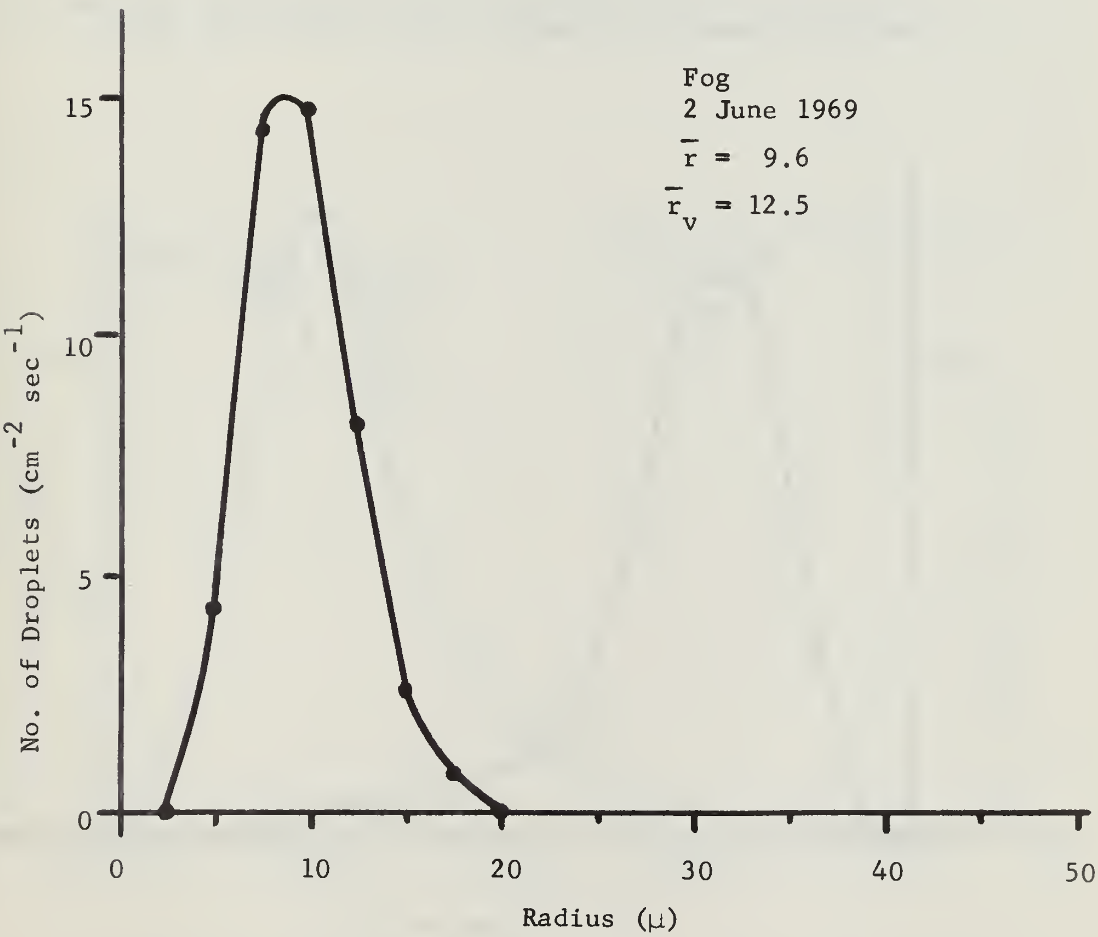


Fig. 17. Droplet-size spectrum in fog atop Spanagel Hall at the Naval Postgraduate School (NPS), Monterey, California.

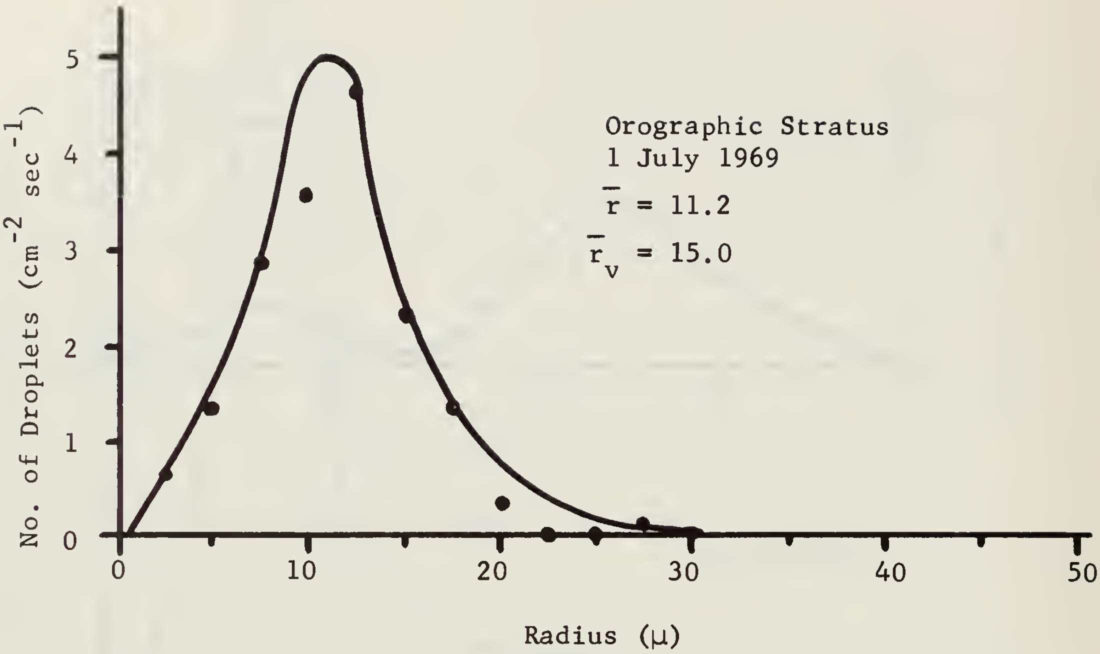


Fig. 18. Droplet-size spectrum in orographic stratus on SE slope of Santa Lucia Range.

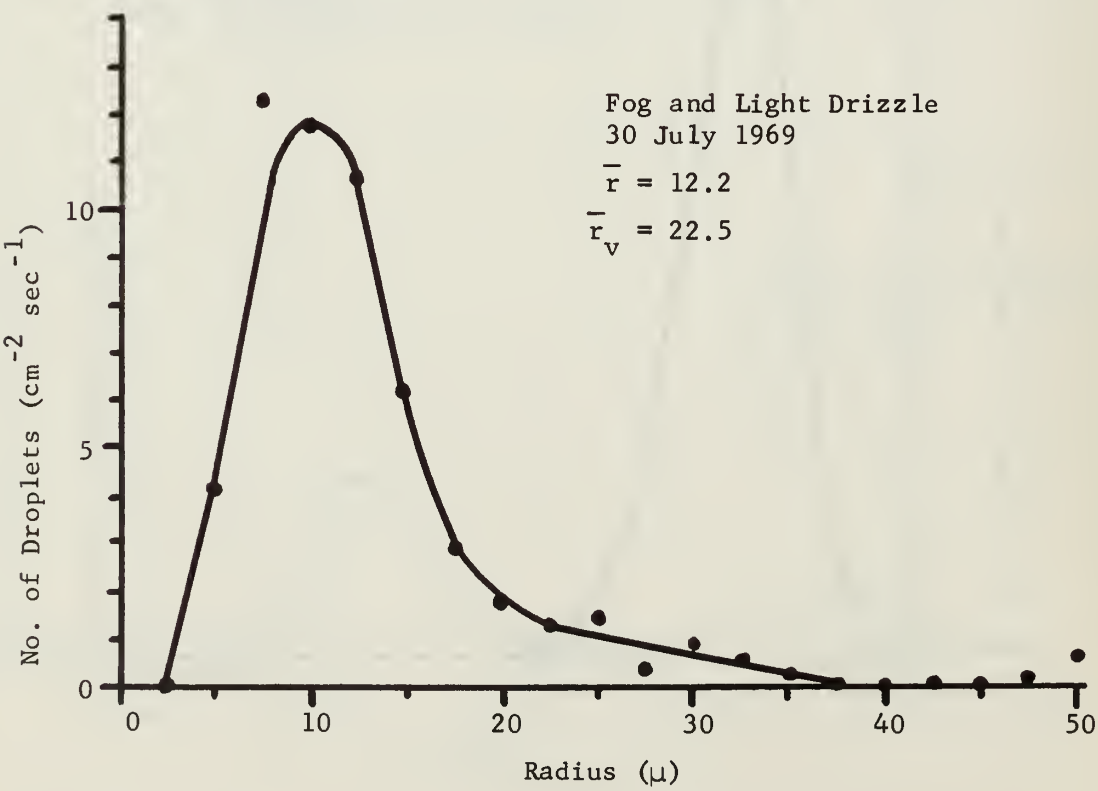


Fig. 19. Droplet-size spectrum in fog and light drizzle at NALF Monterey.

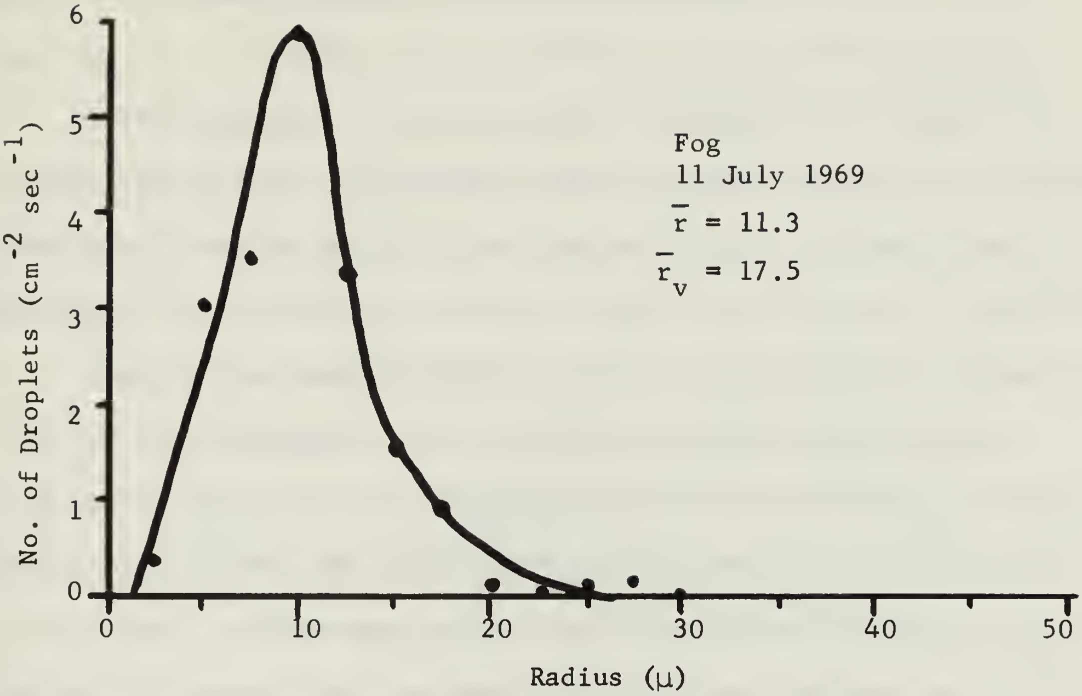


Fig. 20. Droplet-size spectrum in fog at NALF Monterey.

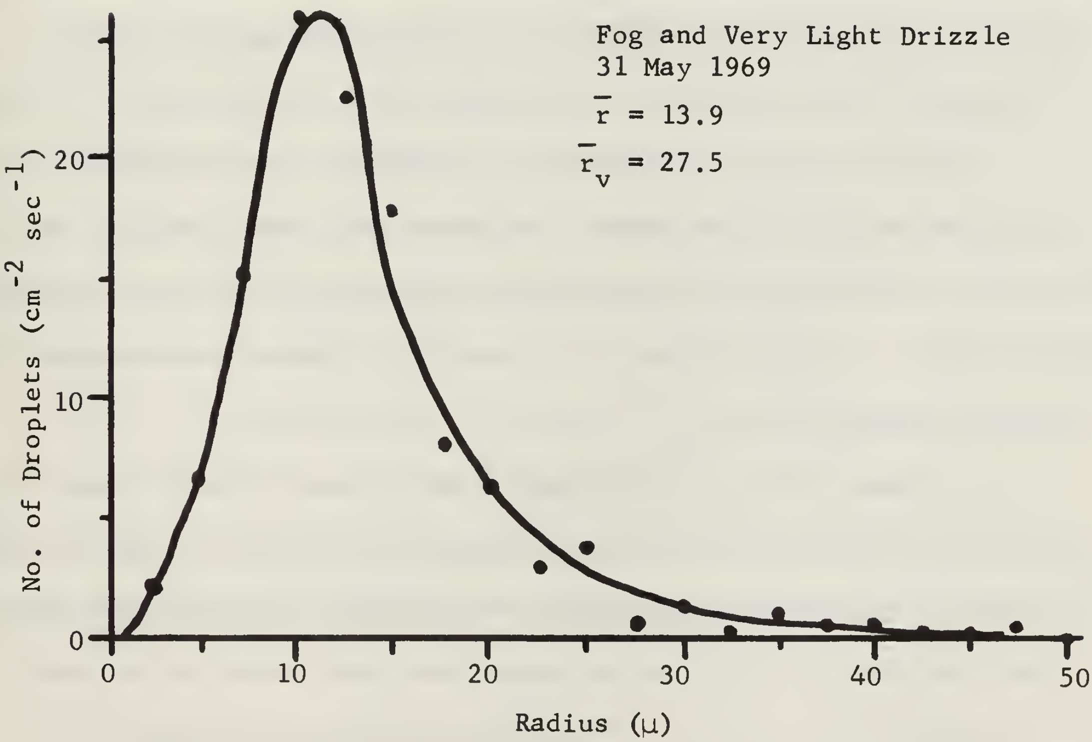


Fig. 21. Droplet-size spectrum in fog and very light drizzle at NALF Monterey.

is fixed. This is an important factor in a dynamic situation in which the turbulent eddies are on the order of a few meters.

Visual evidence of the scale of these eddies was observed during every case of sampling. The transmissometer light beam ranged from unobstructed to very indistinct within a few seconds. The transmissometer indicator showed abrupt changes of hundreds, and occasionally thousands, of meters with only a very slight change in the wind.

On a larger scale, an erroneous input could result when visibility is not the same in all directions. In a typical case, the transmissometer indicated 800 m, visibility to the south was less than 400 m, and upwind to the north, was greater than 3000 m. Thus, in spite of the nearness to the transmissometer, little confidence could be given to the visibility values recorded for the experiments.

As a result of this deficiency, no great effort was expended in making careful calculations of W, which would have been suspect. Instead, it was considered sufficient to determine the droplet-size spectrum and evaluate the hand-held slide method of sampling.

In view of these objectives, it is noted that the droplet-size spectra are well delineated. The peaks are clearly defined in each of the figures and are in substantial agreement with the study by Jiusto (1964). In this respect, the hand-held slide method appears completely adequate.

Two cases stand out clearly from the others. Figs. 15 and 16 illustrate the distinctly different droplet distribution in the presence of drizzle. The bi-modal appearance is prominent but beyond the scope of this discussion. In all other cases, the peaks occur within the radius range of 7.5 - 12.5 μ. The computed values for $\bar{r}$ and $\bar{r}_v$ in those cases are within the ranges 9.6 - 13.9 μ and 12.5 - 27.5 μ respectively.

For the purpose of evaluating the hand-held slide method, the eight samples from the last case were examined more closely. The capabilities of the method and its limitations were thus made more prominent.

Fig. 22 clearly shows the effect of the sampling duration on the crater concentration. Based upon exposure time alone, the concentration would have been approximately equal. Unfortunately, exposure times on the order of one second were not used; therefore, it can only be assumed that the normalized concentration would have been much greater than either shown in this figure. It is also noted that the wind difference of one knot is not apparent in Fig. 22. Thus, a serious drawback of the method is the aerodynamic effect around the slide (all Case VIII slides held at 45 degrees).

Figs. 23 and 25 illustrate the effect of a change in visibility upon the normalized droplet concentration. A comparison of the two figures reveals a greater density due to the greater wind. This is not at odds with the previous conclusion. During these samples (Fig. 25) the wind was extremely variable which apparently produced the effect of multiple short exposures.

Fig. 24 illustrates the difference in normalized concentration based upon wind difference alone, four vs. two knots. Once more the effect of the airstream is obvious. At a mean wind speed of four knots the protective cushion appears to be maintained more effectively than at two knots.

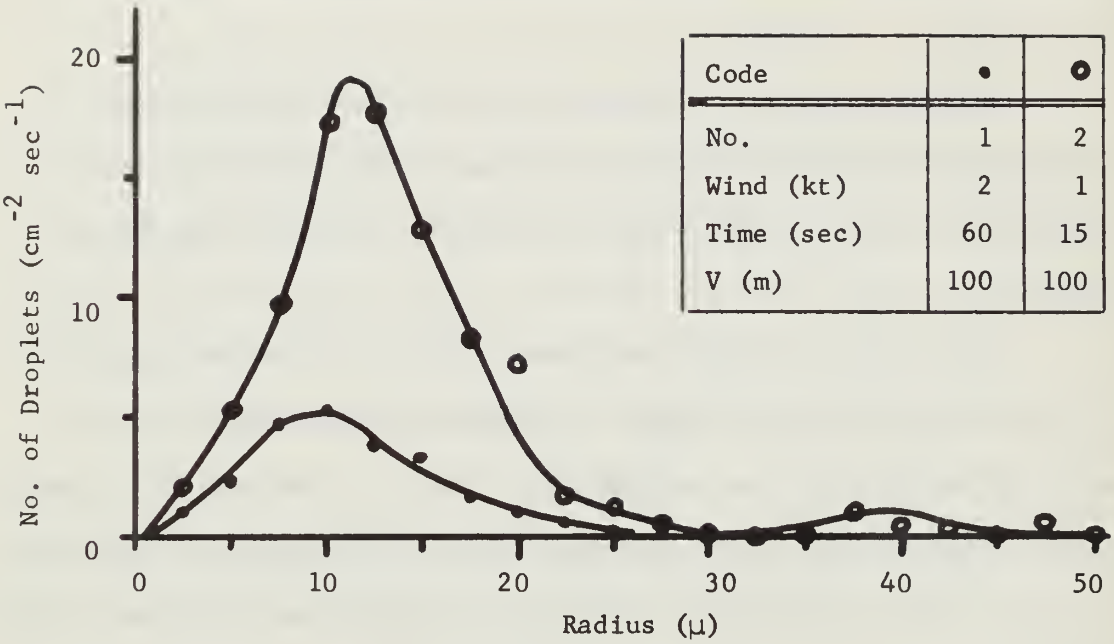


Fig. 22. Comparison of fog samples showing the effect of exposure time overriding that of wind speed on the droplet concentration.

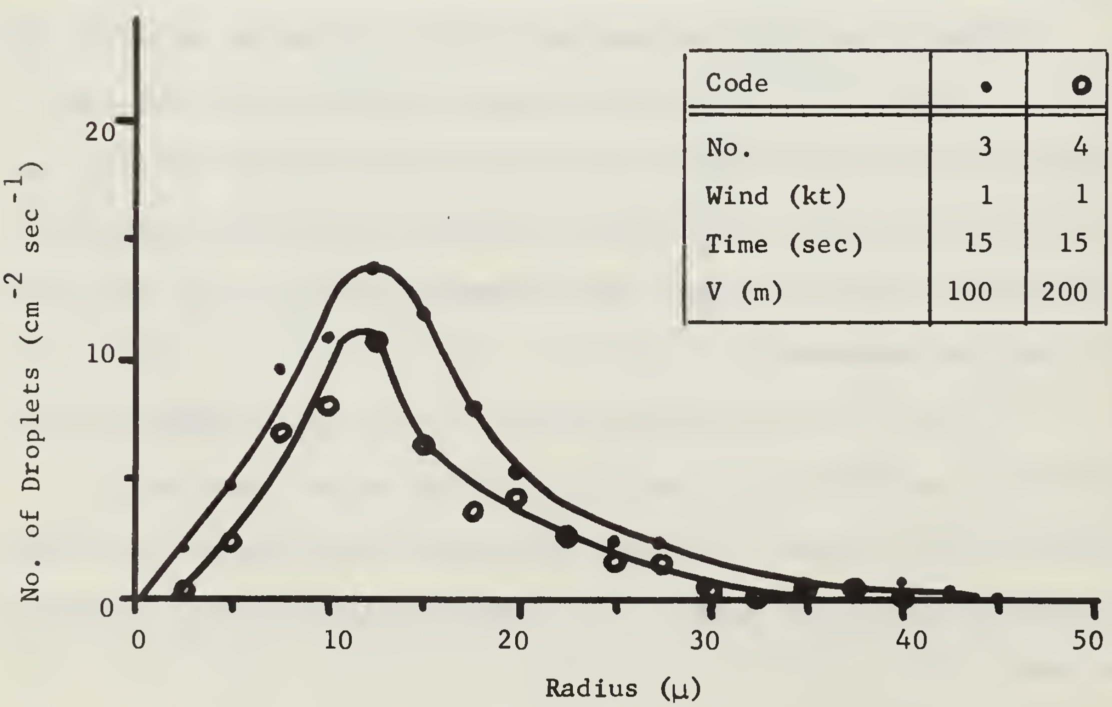


Fig. 23. Comparison of fog samples showing the effect of an increase in visibility, at a wind speed of one knot.

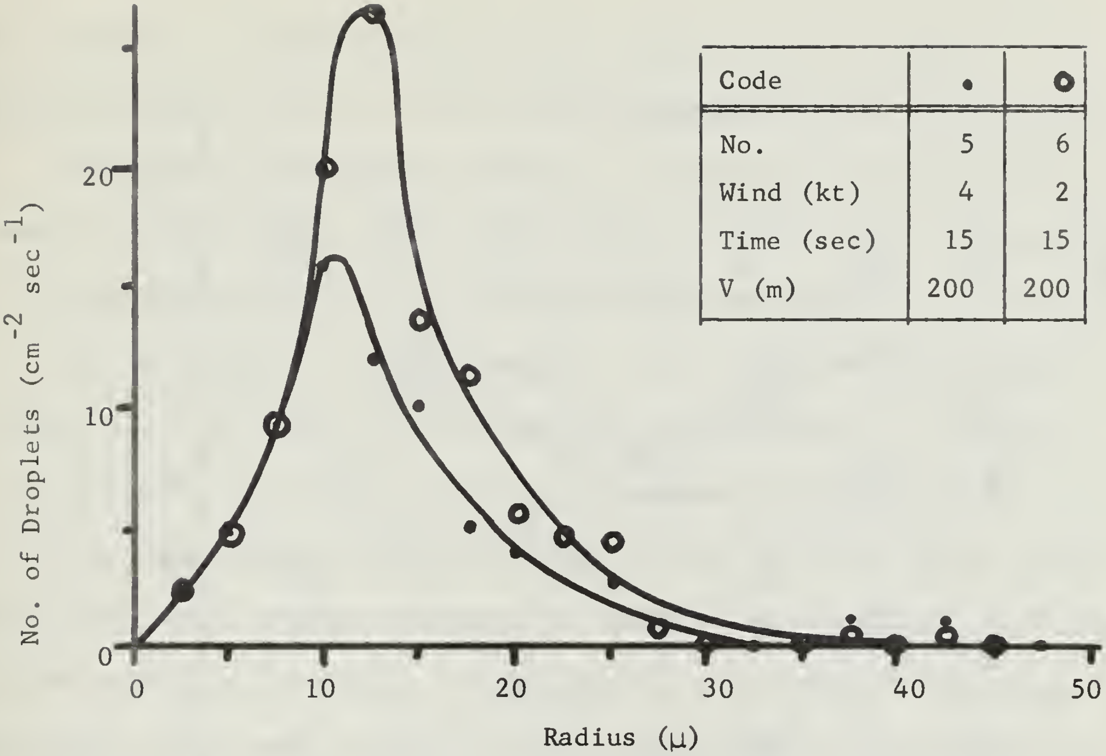


Fig. 24. Comparison of fog samples showing the effect of wind speed on droplet concentration.

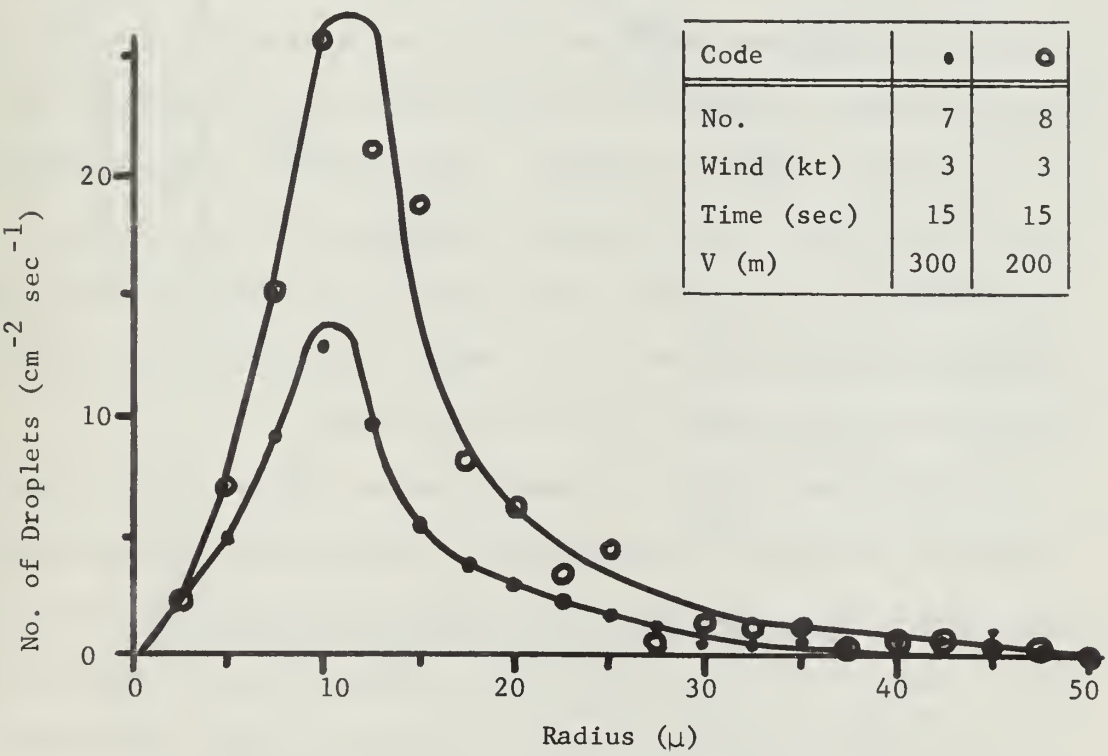


Fig. 25. Comparison of fog samples showing the effects of a decrease in visibility, at a speed of three knots.

Figs. 26 and 27 depict a chronological sequence of various droplet-size classes through the sample case VIII. In this series, the schedule of sampling was not adhered to. Instead, samples were obtained at irregular times to show the variability. Okita (1962) used this form of drawing to illustrate aging effects but it serves equally well to illustrate "noise" in the data. As indicated, the figures reflect "smoothed" or extracted data from the curves of Figs. 22 - 25. Based upon an assumption of homogeneous air, with respect to droplet-size distribution, Figs. 26 and 27 together clearly indicate the region of noise. Thus, there are apparent discrepancies in the first three radius intervals. This is not surprising due to the subjectivity with which the size was initially determined. However, this is considered a consequence of the evaluation technique rather than the sampling technique.

The evaluation technique was weak in that an additional process of photomicrography was introduced. This was a necessity, however, for physical reasons. Although the process proved to be advantageous in sizing craters, it had its drawbacks. Some difficulty was encountered in obtaining sharply focused images. This certainly led to some erroneous counts, particularly with respect to the smaller droplet sizes. In terms of objectives, however, the method is certainly valid and preferable to more extended use of the microscope.

Careful analysis of the data indicates that the tilted slide orientation is superior to the vertical. The spectrum from the tilted slide contains less noise and is more closely related to the various models. The vertical slide produced more large craters as expected but these were randomly located. Proper evaluation of these would require analysis of a much larger area of the slide. Hence, it is concluded that

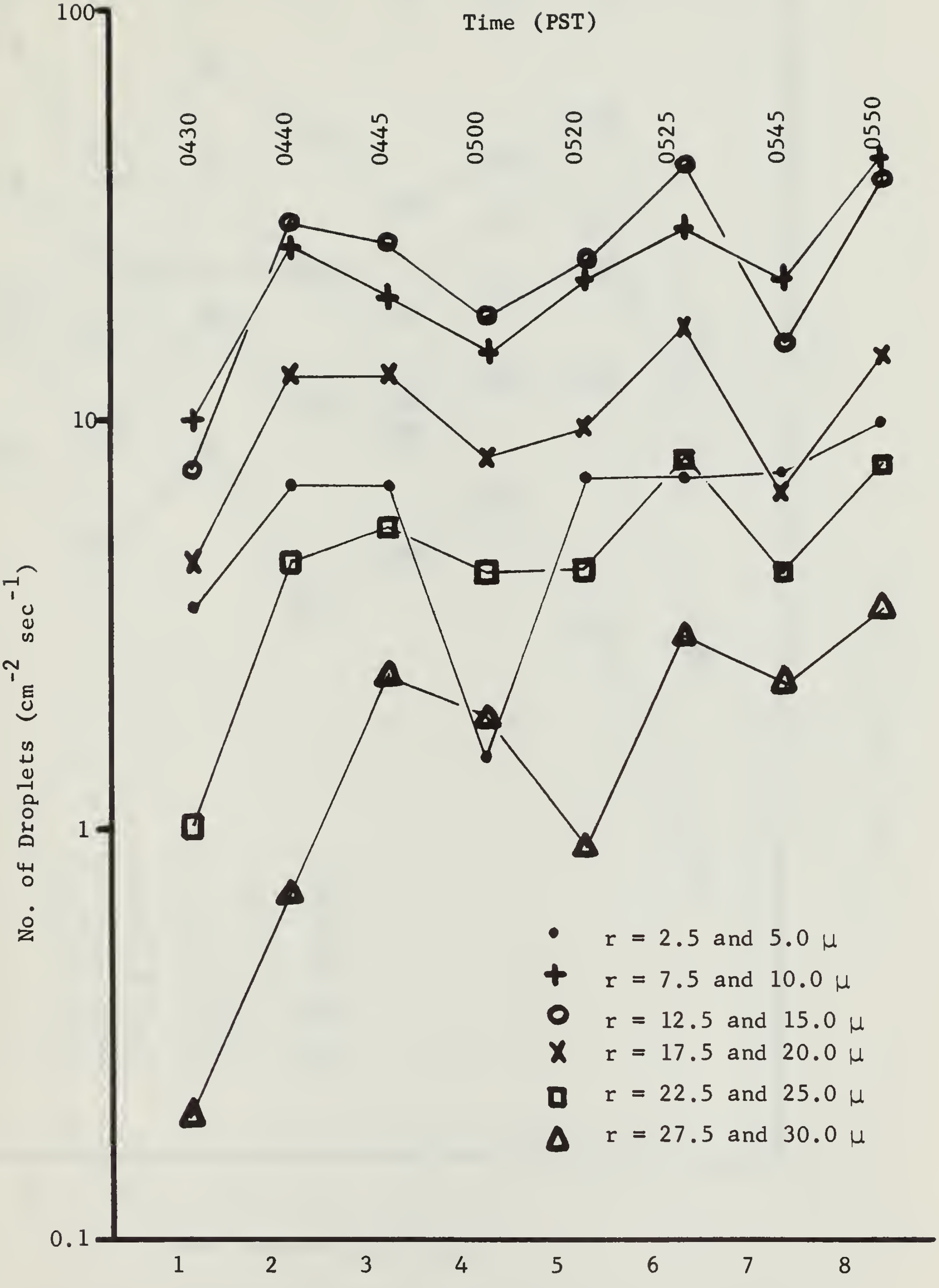


Fig. 26. Chronological cross-section of droplet sizes, in 5-μ increments, at irregular time intervals.

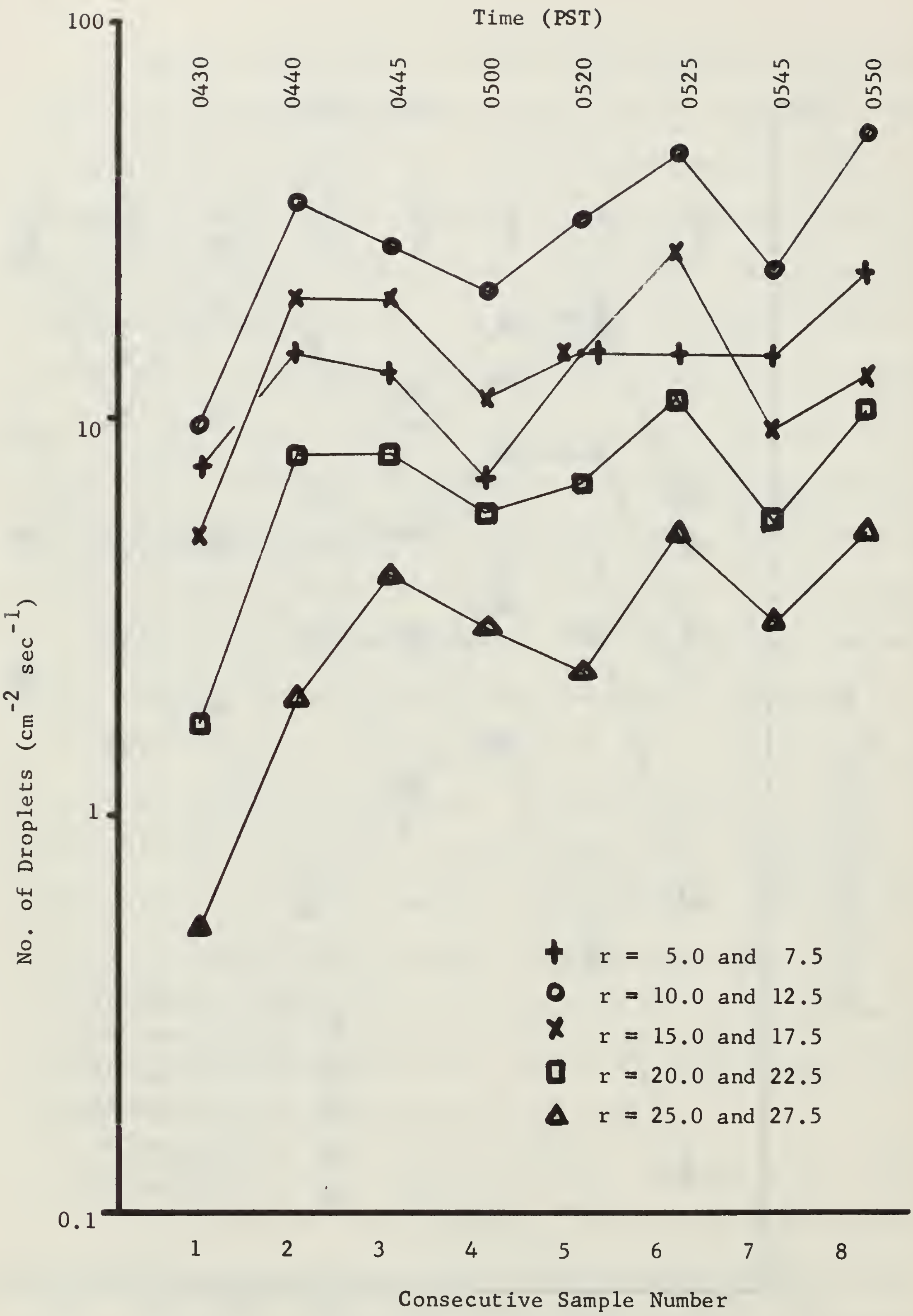


Fig. 27. Chronological cross-section of droplet sizes (> 2.5 μ), in 5-μ increments, at irregular time intervals.

the tilted orientation is best and is adequate for use on a large-scale basis.

IV. FOG DISPERSALS EXPERIMENTS

As discussed in Section II, two of the general methods of fog dispersal which offer probability of success are the use of hygroscopic agents which cause evaporation and surfactants which promote removal of the fog droplets.

Although other methods are potentially effective, these dessicants and surfactants were most interesting for this study. Among other reasons, they were considered better methods for exploitation and, secondly, were more appropriate for small-scale study, requiring less extensive instrumentation, equipment, and facilities.

A. SCOPE OF INVESTIGATION

During initial investigation, exploratory experiments were conducted using a variety of agents, including one surfactant and four hygroscopic solutions. The surfactant was a wetting agent sold commercially as Photo-flo with which the author had previous experience in the field of photography. The hygroscopic agents were sodium chloride, urea, ammonium nitrate, and another photographic chemical sold commercially as Flat Solution.

Although the hygroscopic agents produced visible effects in a fog chamber whereas the wetting agent did not, it was decided to concentrate on the surfactant and other agents of this nature to the exclusion of the dessicants. There were two basic reasons for this decision. The first and foremost was that the hygroscopic agents generally considered as most effective are also very corrosive. Since a practical method of fog dispersal was sought, corrosive agents were considered unacceptable.

Secondly, during the course of the investigation, additional work was published (Cornell Aeronautical Laboratory, Inc., 1969; Kochmond and Pilié, 1969) discussing the use of NaCl. Other work dealing with dessicants, currently in progress, under the auspices of the Earth and Planetary Sciences Division of the Naval Weapons Center, China Lake, California also became known to the author. Thus, it was apparent that an investigation of surfactants would prove to be of greater interest and perhaps of more value.

As a consequence, it was decided to conduct experiments in the laboratory using common detergents in search of a surface active agent having the capability of producing artificial dissipation of fog.

B. METHOD OF APPROACH

The initial plan was to experiment with fog generated with a bell jar. The object was to work with fog at normal temperatures and pressures. Early experiments revealed the difficulties involved and the need for new equipment or the modification of existing equipment to make it suitable for this type of experiment. Recognizing the inherent limitations of the equipment for fog modification experiments, it was decided that a more practical solution would be the introduction of steam into a large chest-type food freezer.

The freezer and steam proved inadequate because of the lack of confining walls and inadvertent creation of supercooled fog. Thus a hood of clear thin vinyl mounted on a wood framework was built to fit over the freezer compartment. Although this proved to be a better fog chamber, it, too, was lacking in several respects. Most important of these was the lack of a standard or control fog, and limited space in which the spray could interact with the fog droplets.

The above factors led to the final version of fog chamber modeled after that used by Jia-Dong (1962). This chamber (Fig. 28) provided an ample volume of fog with which to work, a 2.4 m fall distance, and most importantly, a control fog. Experiments were then conducted exclusively in this chamber under various conditions of fog and seeding agents to produce artificial modification of fog using common household detergents.

C. EQUIPMENT AND INSTRUMENTATION

1. Fog Chamber

Since most of the experiments were conducted in the later version of the fog chamber, discussion will be limited to that particular device.

The chamber was constructed of 1 in x 2 in (1.9 x 3.8 cm) common grade lumber. The framework for a box 4 ft x 4 ft x 8 ft (1.22 x 1.22 x 2.44 m) was assembled and covered with 4-mil (0.1 mm) clear vinyl. This material was obtained in a roll, 48 in x 100 ft (1.22 x 30.5 m). Only the sides and the square top were actually covered since the chamber was to sit directly on the brick floor. Masking tape was used to both reinforce the vinyl edges and secure them to the framework. The edges were then stapled down to prevent the tape from becoming loosened. Openings were left near the top and bottom for venting, introducing steam and spray, and for obtaining gelatin samples of the fog droplets. A roller type window curtain was painted flat black on both sides and mounted at the bottom of the box. It was equipped with a lanyard for unrolling upward, dividing the chamber into two equal compartments. Since one side was to be used as a control side and the other as a seeding side, it was necessary to add a baffle along the

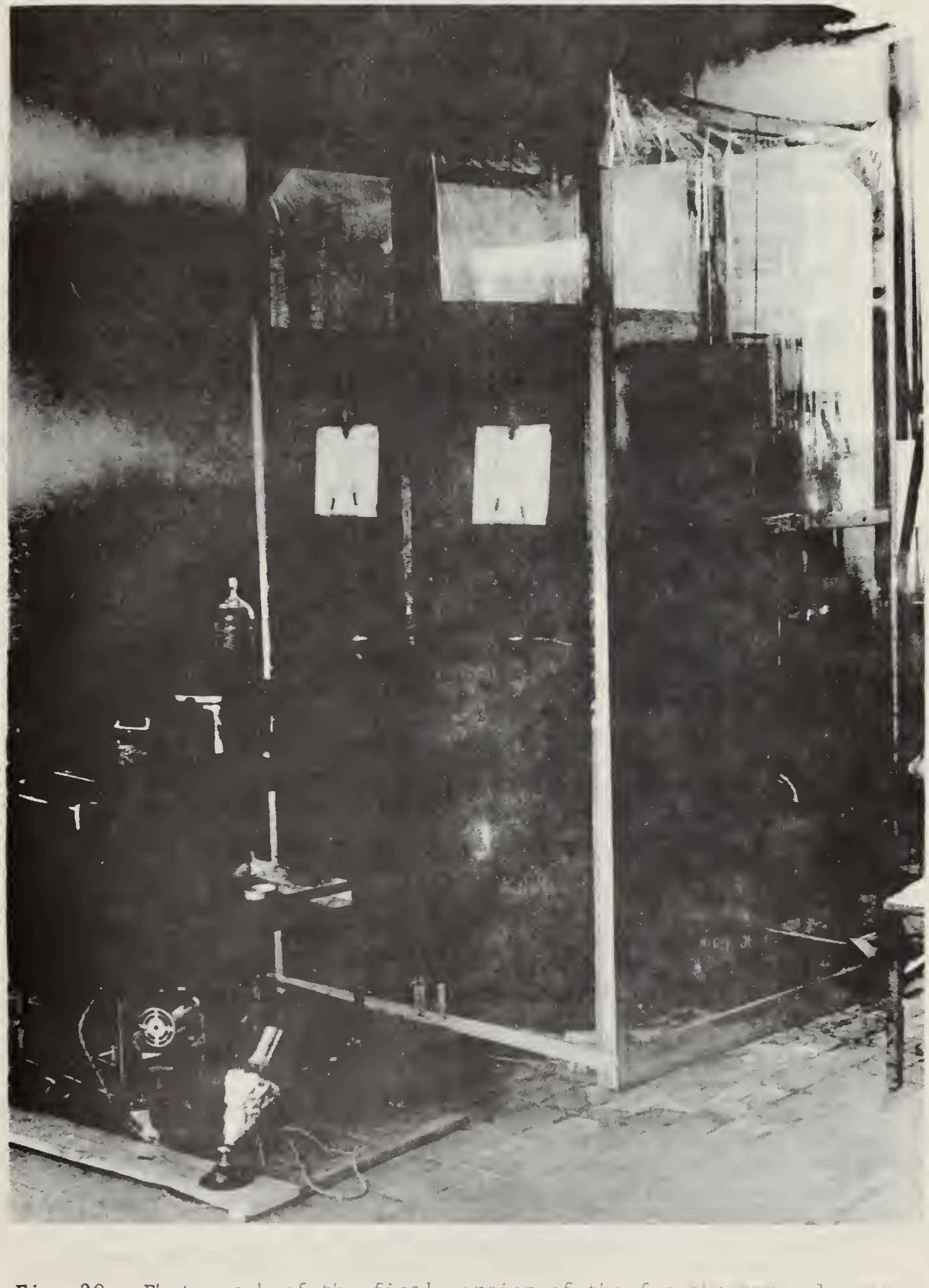


Fig. 28. Photograph of the final version of the fog chamber. In use the lamps were mounted atop the chamber and lighted the targets from the front. Note the raised curtain and the steam inlet lines from a "Tee" fitting.

sides of the box at the curtain ends. For this purpose, lengths of Masonite, 10 cm wide, were secured to the guide rails. The smooth surface of the hardboard was faced against the curtain to prevent snagging. A skirt of the vinyl material was draped from the top of the box to provide a baffle there. Although a perfect seal between the compartments could not be obtained by this method, the separation was excellent. A very dense fog could be maintained in one side for more than five minutes with negligible leakage into the other compartment.

Initially, condensation on the inner walls was a major problem. This was corrected by the use of photo-flood lamps near the vinyl walls. By adjusting the position of the lamps and by using masking cones to enclose the beams, hot spots of any desired size could be maintained on the walls, thus preventing condensation on the inner surface.

2. <u>Steam Generator</u>

Steam was generated by the use of a water-filled electric pressure cooker. The pressure valve was replaced by a heavy rubber hose through which the steam was carried to the fog chamber. This type of generator is considered superior to others considered because of its convenience and because it is a quick-heating appliance.

3. <u>Spray Generator</u>

At various times, different types of spray apparatus were used: A DeVilBiss No. 44 nebulizer, a DeVilBiss No. 251 atomizer, and a Sprayon Products "Jet-Pak" spray attachment. The latter accommodated 100 ml glass jars, a convenient size for the experiments, and produced a consistent spray, using a pressurized gas container. Thus, the spray attachment was the standard equipment used throughout the series of experiments.

Droplet sizes produced by the sprayer were determined for each of the solutions used. This was the basis for subsequent comparison with precipitation samples obtained from the seeded fog.

4. Instrumentation

Gelatin slides previously discussed were used to determine the droplet sizes as they fell to the bottom of the chamber. Again, time of exposure was determined by the crater density desired. For this purpose, a two-inch space had been left under the framework on the two sides of the chamber which spanned both compartments. The side covering formed a skirt over this opening and reached the floor. Sampling was accomplished by placing a slide on the end of a 0.6 m board, lifting the vinyl skirt, sliding the board full length into the chamber (either compartment), and withdrawing it again after the desired exposure time. The length of the board assured that the slide would be located in the center of the compartment each time and would still allow the skirt to be dropped during exposure. After exposure, the slides were left briefly within the chamber, but under the projecting ledge of the framework, to ensure complete cratering by the smaller droplets.

A second method of sampling was used in the later experiments. Identical cardboard boxes were placed in the two compartments. Openings were cut in the vinyl sides for access. The slides were then inserted through the ports and covered with halves of cardboard tubes. This permitted the slides to reach equilibrium with the compartment before exposure. Exposure was accomplished by simply removing the cardboard shelter for the desired time and replacing to terminate the exposure. Except during moments of access, the ports were sealed by a vinyl skirt over the outer surface.

Provision was made for photographic documentation. The divider curtain, painted flat black, reduced the reflections within the compartment to a minimum and permitted photographs to be taken of lighted targets through the fog. For target illumination, two identical flood lamps were mounted atop the fog chamber with their beams projecting through the fog to the targets as illustrated in Fig. 29. Thus the light reaching the camera had passed through the fog twice with a total fog path of 3.12 m. The lamps were equipped with foil-wrapped cardboard tubes to confine the light to beams and reduce the stray light. Further, the lamps were operated from a 0 - 140 volt variac to permit adjustment to any desired intensity. Some difficulty was experienced in obtaining balanced illumination on the targets. For this purpose, it would have been better to use a voltage dropping resistor in series with one lamp and the other on the variac. Two large reflectors and 500 w photoflood lamps near the chamber wall kept a rather large area free of condensation. When photographs were desired, the lamps were merely switched off briefly.

Photographs were made using a Canon FT 35mm camera with a 50 mm f/1.4 lens. Kodak Tri-X black and white film was exposed at 1/15 sec at f/2.8.

Temperature was monitored by standard meteorological glass rod mercury thermometers. These were inserted full length through holes in the framework of the outer walls of the two compartments.

D. EXPERIMENTAL PROCEDURES

The laboratory investigation consisted of two phases. The first of these involved preliminary exploratory experiments in which various

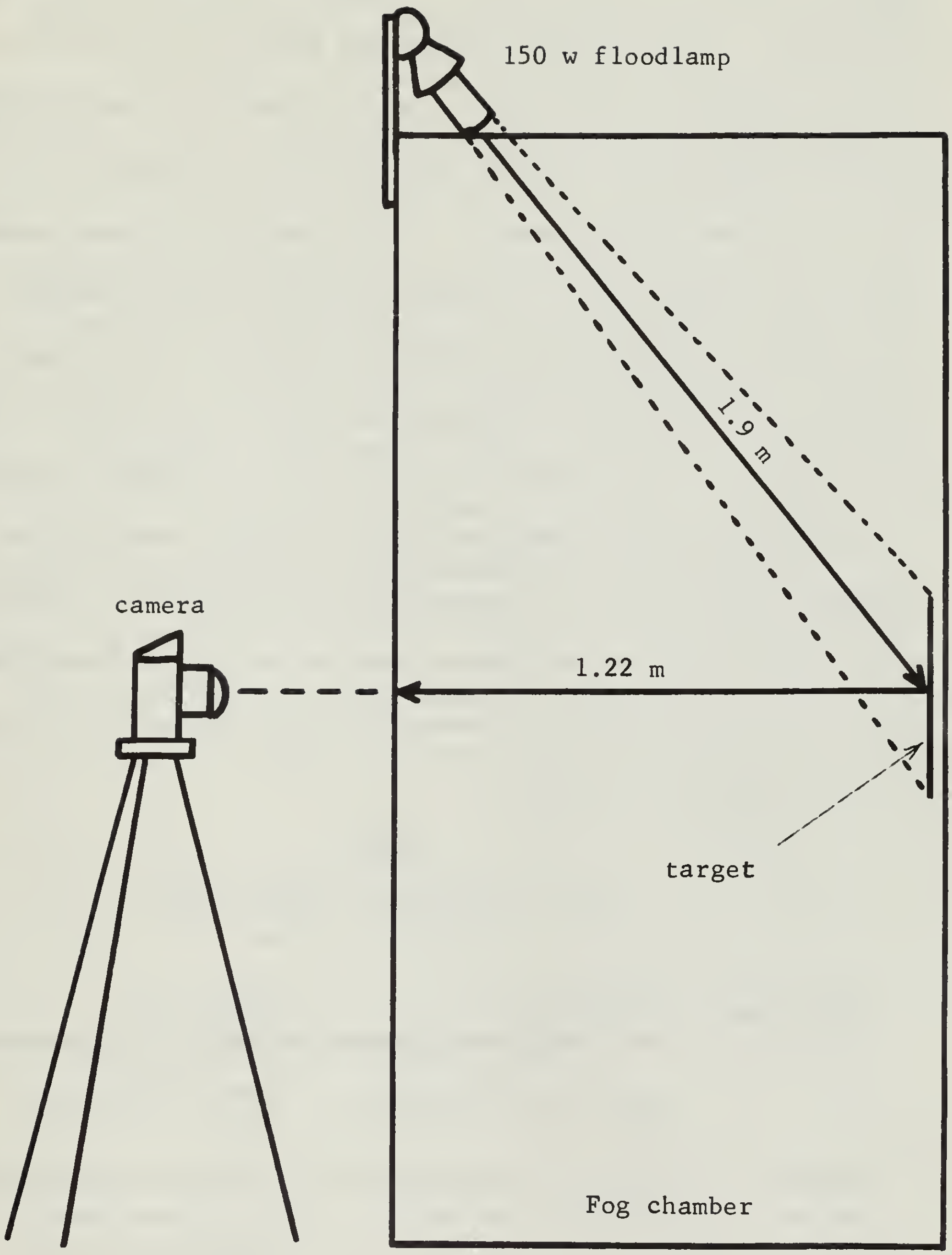


Fig. 29. Schematic diagram of target illumination for photographic documentation.

substances (Table V) were used to produce an effect upon the fog in the chamber. Since sodium chloride has been used in successful attempts at fog modification (Kochmond and Pilié, 1969) this and the other solutions (saturated) involved were tested to determine the visible effect produced in the chamber. In this manner, a rough comparison could be made between the fog chamber and the field experiment. Since very noticable effects were produced by the use of the common salt solution, the chamber and the experiment were, in general terms, valid. Thus, experiments with other substances were considered justified.

The second phase of experimentation involved working with three detergents in an effort to determine their abilities to produce dissipating effects in the fog chamber under a variety of conditions. During this phase, more complete documentation was obtained and the experiments were more rigidly controlled.

TABLE V

List of Household Agents Tested

Name Used	Trade Name	Manufacturer
All	Automatic Dishwasher ALL	Lever Brothers Co.
Axion	Axion Pre-soak Formula	Colgate-Palmolive Co.
Borax	20 Mule Team Borax	U. S. Borax and Chemical Corp.
Calgon	Calgon Water Conditioner	Calgon Corp.
Cascade	Cascade for Automatic Dishwashers	Procter & Gamble
Downy	Downy Fabric Softener	Procter & Gamble
Service	Service Brand Detergent	Calusa Chemical Co.

1. <u>The Basic Experiment</u>

Procedures involved in the basic experiment were very simple. Distilled water was used in the pressure cooker to preclude tainting the experiments with an unknown factor. While the water was heating, the lamps were arranged around the fog chamber to maintain the desired clear spots for visual inspection of the interior. In a very short time, steam was available for charging the entire fog chamber. When this step was complete, the curtain was raised to ensure that it, too, was wetted by condensate. The pressure cooker thermostatic temperature control was reduced and the fog allowed to dissipate naturally. This step ensured that subsequent experiments would be consistent. The curtain was lowered and the entire fog chamber filled with fog once more. When filled and in equilibrium, the chamber was divided and the desired solution was sprayed into the seeding compartment through the opening near the top. If desired, a reference solution (usually tap water) was similarly sprayed into the control fog. The light beams and the targets were then watched carefully for indications of precipitation or thinning. In this step, observations in the seeded fog were carefully compared to those made in the control side.

Later experiments were observed more closely and more complete documentation was made. This involved monitoring the temperature in both compartments, photographic records of observations, time-controlled spray applications, and fog sampling in both chambers at fixed intervals. In addition, samples of the spray droplets were obtained again after the experiment, with the same solution. These samples were intended to be the reference against which comparisons could later be made. Unfortunately, gelatin is not well suited to these conditions. Attempts to obtain other than very brief samples produced softening of the entire film and the loss of the record. However, photographic documentation remains to support the observations.

E. DISCUSSION OF RESULTS

The agents included in the final phases of experimentation are shown in Table VI. The ability of two agents, Calgon and Cascade, to produce repeated clearing of the fog was impressive. In no case did either of these fail. Those achieving results described as inconclusive generally produced slight improvement in visibility. They did not, however, consistently match the ability of plain tap water. Those agents producing negative results not only failed to match the tap water reference agent in ability but also failed to match natural dissipation of fog in the control side.

In this respect it must be pointed out that the experiments were biased against success of a seeding agent. The left (with respect to the photographer) side of the chamber dissipated somewhat more rapidly than the right. Therefore, the left was used as the control side to establish greater confidence in those agents achieving success against unfavorable odds.

Fig. 30 presents a comparison between the photographically recorded results of experiments with Calgon and tap water. Time t = 0 was the time at which the agent was sprayed into the right side of the chamber. Comparison of results obtained by Cascade, Service, and sodium chloride are shown in Figs. 31 - 33 respectively. Fig. 34 compares the effects of Calgon and Cascade on opposite sides of the fog chamber. The sides are reversed in Fig. 35 to indicate the superior agent. As indicated in

TABLE VI

Seeding Agents Used and Results Obtained During Final Phases of Fog Modification Experimentation

Agent	No. of Experiments	Results
(Detergents and water softeners)		
All	7	Inconclusive
Axion	6	Negative
Borax	10	Inconclusive
Calgon	19	Successful
Cascade	14	Successful
Downy	8	Inconclusive
Photo-flo	10	Negative
Service	14	Limited Success
(Other agents used as reference)		
Ammonium nitrate	4	Very successful
Calcium chloride	3	Limited success
Sodium chloride	4	Very successful
Water	29	Reference - limited success as an agent
Water, distilled	4	Limited success

the photographs, Cascade did indeed appear superior to Calgon by a slight margin.

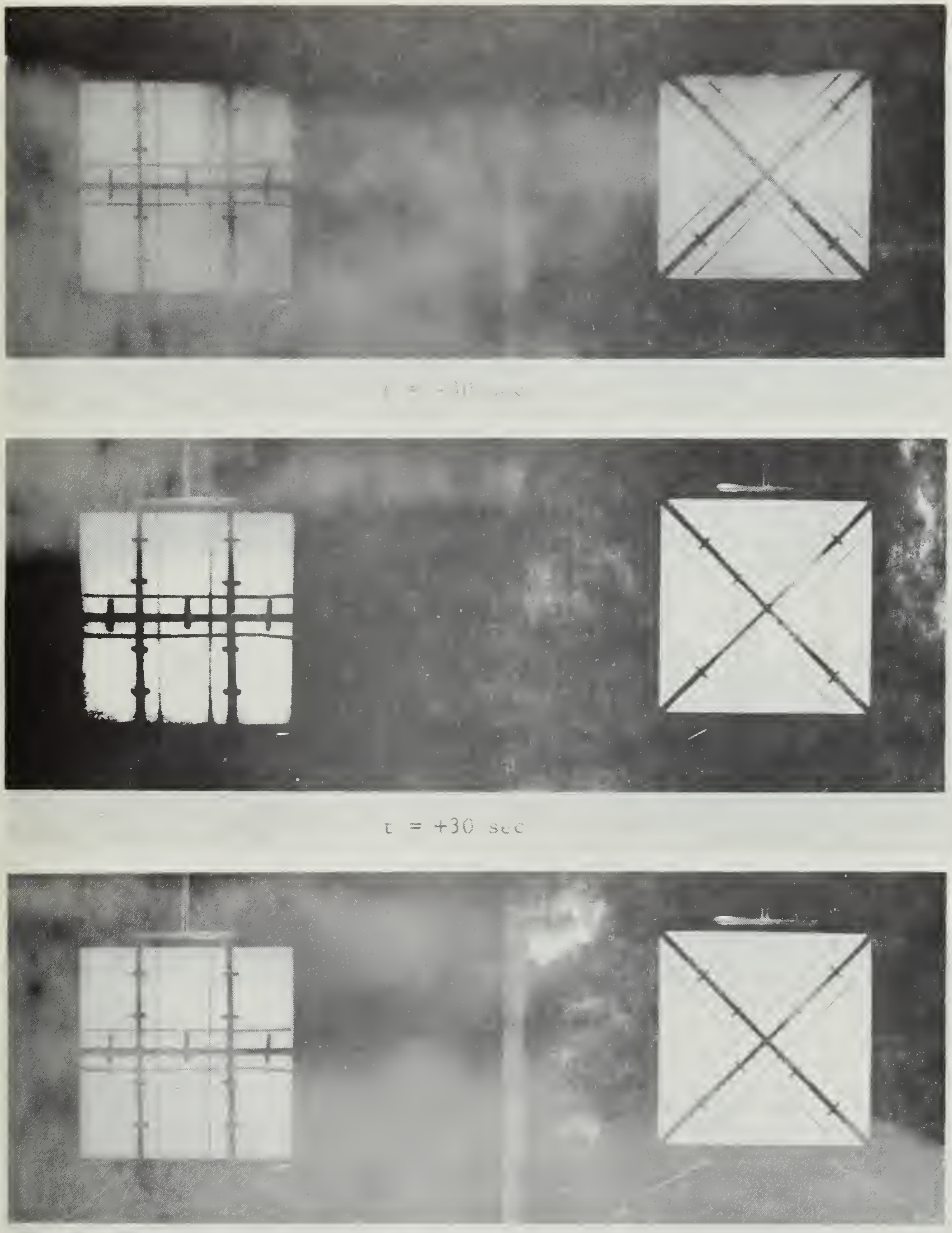
Because of the gelatin softening previously mentioned, comparison of samples from the fog-filled chamber with the calibration slides is invalid. The calibration slides were obtained at a lower ambient temperature and therefore produced excellent droplet craters. The fog modification samples, however, were poor. In many cases, the coating was completely liquified. Hence, it became necessary to rely upon the photographic evidence of the actual fog modification.

t = -30 sec

t = +30 sec

Tap water t = +60 sec Calgon

Fig. 30. Comparison of clearing produced by tap water and Calgon. In this and subsequent photographs, agents were sprayed in 2-sec bursts. At t = 0, the agent was sprayed into the right compartment.



[illegible]

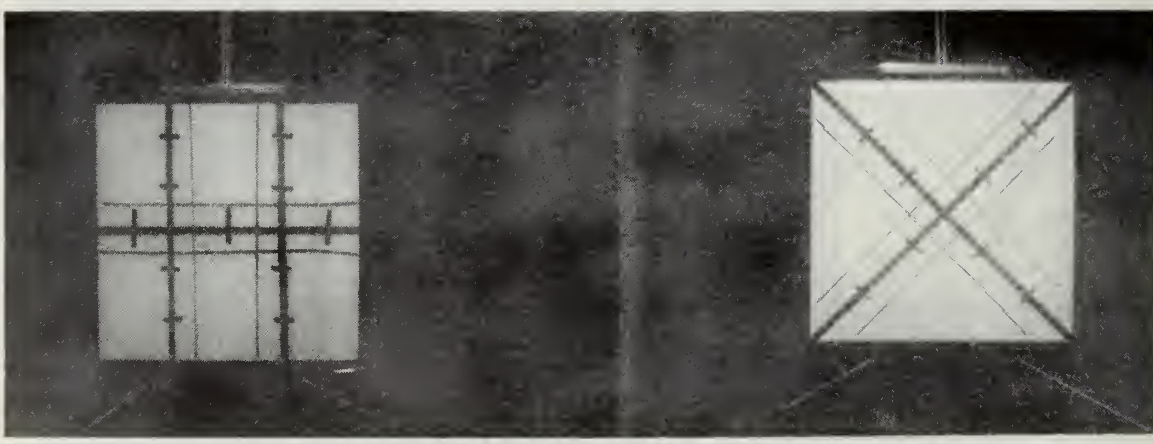
t = +30 sec

Tap water [illegible] Cascade

Fig. 31. [illegible] and Cascade

t = -30 sec

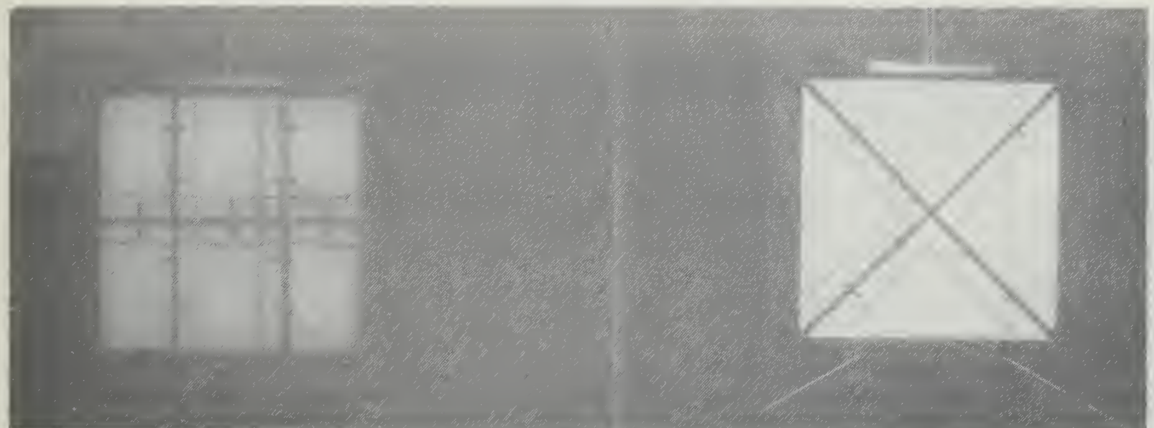
t = +30 sec



Tap water t = +60 sec Service

Fig. 32. Comparison of clearing produced by tap water and Service.

t = -30 sec



t = +30 sec

Tap water t = +60 sec NaCl

Fig. 33. Comparison of clearing produced by tap water and sodium chloride.

t = -30 sec

t = +30 sec

Calgon t = +60 sec Cascade

Fig. 34. Comparison of clearing produced by the two superior surfactants tested, Calgon and Cascade.

t = -30 sec

t = +30 sec

Cascade t = +60 sec Calgon

Fig. 35. Comparison of the clearing produced by the two superior surfactants tested, Cascade and Calgon, in opposite compartments from Fig. 34.

V. CONCLUSIONS AND RECOMMENDATIONS

The various methods of warm fog dispersal are summarized in tabular form in Appendix A. As a result of evaluating these methods, it seems clear that there are four areas which should be studied. These methods are: 1) the turbojet system; 2) dessicants; 3) surfactants; and 4) inversion heating.

As pointed out by the Rand Corp. (1969), there is an urgent need for coordinated research, and an active exchange of information. In this respect, it is recognized that commercial organizations have proprietary rights over their processes; however, until warm fog dispersal becomes more nearly a practical reality, coordinated research and exchange of information is vitally important.

Based upon the findings regarding fog at the Naval Auxiliary Landing Field, it is considered that this would be an excellent location for field testing of fog dispersal methods. These tests should be restricted to early morning hours.

As a result of fog sampling, it was determined that the fogs occurring during May - July 1969 had a droplet distribution centered about a droplet radius of 10 μ with a high frequency of drizzle intermixed. It was further determined that hand-held gelatin slide sampling is adequate for the determination of fog droplet-size spectra on a relatively large scale. Centralized analysis could then be accomplished readily using photomicrography.

In laboratory experiments it was determined that fog dispersal could be achieved by the use of surfactants, three common household detergents: 1) Cascade; 2) Calgon; and 3) Service. It was further established that gelatin slide sampling is unsuited for use in steam-filled fog chambers. A more appropriate sampling technique may be the plastic film replication method reported by Odencrantz and Hildebrand (1969).

The recommended research into the use of surfactants should use this reported work as a point of departure. Optimum strength of solutions and quantity requirements remain to be determined. It was noted, however, that because of low solubility of these detergents, mass requirements were at least an order of magnitude less than for NaCl in mixing saturated solutions. In the laboratory experiments, the surfactants achieved success comparable to NaCl.

The distinct advantage of the surfactants is that they are apparently non-corrosive and would not be harmful, for extended use, to vegetation and airport equipment. Further studies should, however, include this aspect.

APPENDIX A

SUMMARY OF FOG DISPERSAL METHODS

The following tabulation of fog dispersal methods is a brief summarization from the literature. It is intended as a quick reference. The potential of each of the methods has been rated by the author.

1. DEFINITIONS

Impractical means that the method is based upon an unsound principle, is beyond the capability of present equipment, has been demonstrated to be ineffective, or is unacceptable because of risks involved.

Possible means that the method appears sound in principle and may be within the capability of present equipment. Knowledge regarding the practicality of the method is scant.

Study means that the method appears sound in principle and has been demonstrated experimentally under certain conditions. These methods are recommended for future research.

Develop means that the method has been adequately demonstrated in the laboratory and, to some extent, in the field. Only refinements are considered necessary prior to operational use.

2. TABULATION

Name of Proponent	Principle or Method	Potential
Methods Involving the Physical Removal of Water Droplets from the Air		
ENTRAPMENT		
Hori	Foilage	Impractical
Schmieschek	Rotating sieve	Impractical

Various	Baffles and screens	Impractical
Various	Underground ducts and baffles	Impractical
	MECHANICAL SWEEPING	
Buxton et al. Magano et al. Plank	Water drops	Possible
Houghton and Radford Humphreys Pauthenier	Water drops, with electrical charge	Possible
Houghton and Radford	Sand particles, with electrical charge	Possible
Facy	Soap bubbles	Impractical
	COALESCENCE MODIFICATION	
Jiusto et al. World Weather, Inc.	Surfactants	Study
Various	Sound field	Impractical
	ELECTRICAL METHODS	
Arthur D. Little, Inc.	Sprayed agent, charged	Impractical
Cottrell	Repulsion, charges by corona discharge	Impractical
Hagen	Ionic current	Impractical
Jiusto et al.	Ionic surfactants	Study
Junge	Attraction, charges created by two aircraft	Impractical
Lieberman	Triboelectric powders	Impractical
MacCready and Mee	Attraction, charges by aircraft wingtip discharge	Impractical
Pilié et al.	Attraction, corona discharge by alternating current	Impractical
World Weather, Inc.	Ionic surfactants	Study

Methods Involving the Evaporation of Water Droplets		
HEAT		
Diesel Power, Inc.	Inversion mixing	Impractical
FIDO	Convective heating	Develop
Hagen	Inversion mixing, electrically induced	Impractical
Hicks	Inversion mixing, by helicopter downwash	Study
Houghton and Radford	Chemical reaction	Impractical
Jet Engines	Convective heating	Study
Magano et al.	Inversion mixing, entrainment	Study
Telkes	Solar heat storage	Impractical
Todd and Nickerson	Jet engine, for aircraft carrier use	Study
Various	Carbon seeding over the fog	Impractical
Various	Radiant heat	Impractical
Various	Radiation, electromagnetic	Impractical
Wayne and Bell	Heat exchanger	Impractical
Wayne and Bell	Refrigeration plus feedback	Impractical
DESSICATION		
Brandau and Kooser	"Secret" chemical, reportedly NaCl	Possible
Cleaver-Brooks	Vaporized $CaCl_2$	Impractical
Houghton and Radford	$CaCl_2$ dessicator	Impractical
Houghton and Radford	$CaCl_2$ solution	Possible
Jiusto et al.	NaCl preseeding	Study
Kochmond and Pilié	NaCl particles	Study
World Weather, Inc.	NaCl solution, ionized	Study

Methods of Fog Prevention		
Bigg et al.	Surfactant, vaporized	Study
Jiusto et al.	NaCl, preseeding	Study

LIST OF REFERENCES

Appleman, H. S., 1968: First report on the air weather service weather-modification program. AWS Tech. Rept. 203, ASTIA AD-671 995, USAF Air Weather Service, Scott AFB, Ill., 13 pp.

Arthur D. Little, Inc., 1956: Warm fog and stratus cloud dissipation. Final Report to Signal Corps, Contract DA-36-039 SC-64569, ASTIA AD-204 315, Cambridge, Mass., 85 pp.

Beckwith, W. B., 1968: An analysis of airport fog dispersal operations. Proc. of the First Nat'l Conf. on Weather Modification, Amer. Meteor. Soc. and State University of New York, Albany, N. Y., 361-371.

Beers, N. R., et al. (ed.), 1945: Numerical and graphical data. Handbook of Meteorology. McGraw-Hill Book Co., Inc., New York, N. Y.

Berg, T. G. O., G. C. Fernish, and T. A. Gaukler, 1963: The mechanism of coalescence of liquid drops. J. Atmos. Sci., 20, 153-158.

Bigg, E. K., J. L. Brownscombe, and W. J. Thompson, 1969: Fog modification with long-chain alcohols. J. Appl. Meteor., 8, 75-82.

Buxton, E. B., R. A. Chechile, and J. G. Davis, 1968: Feasibility study for a rotor lifted water droplet system to disperse warm fog. Rept. SCR 371 by United Aircraft Corporate Systems Center, NWRF 43-0368-135, ASTIA AD-833 570, U. S. Navy Weather Research Facility, Norfolk, Va., 93 pp.

Coons, F. G., 1968a: Project cold fan--final report. Final report on the air weather service FY 1968 weather modification program, Vol. 1, Tech. Rept. 209, USAF Air Weather Service, Washington, D. C., 41-56.

_______, 1968b: Project warm fog--final report. Final report on the air weather service FY 1968 weather modification program, Vol. 1, Tech. Rept. 209, USAF Air Weather Service, Washington, D. C., 5-20.

Cornell Aeronautical Laboratory, Inc., 1969: Warm fogs. Research Trends, 17, 20-24.

Downie, C. S., and R. B. Smith, 1958: Thermal techniques for dissipating fog from aircraft runways. ASTIA AD-160 752, AFCRC-TN-58-477, AF Surveys in Geophysics No. 106, 38 pp.

Dubois, E., 1965: Fog dispersal on runway approaches. Weather, 20, 313-315; 318.

Fabre, M. R., 1968: Improvement of visibility over airport runways during foggy weather, part I: study of fog and its effect on air traffic: procedures of improving visibility. Transl. by Atmospheric Sciences Lab., ASTIA AD-831 589, White Sands Missile Range, N. Mex., 55 pp.

Fenn, R., and H. Oser, 1962: Theoretical considerations on the effectiveness of carbon seeding. USASRDL Tech. Rept. 2258, U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J., 30 pp.

Fleagle, R. G., and J. A. Businger, 1963: An Introduction to Atmospheric Physics. Academic Press, New York, N. Y.

Hagen, G. E., 1961: Study, development, and testing of a fog clearing device. Rept. No. 3 (final), Contract DA-36-039 SC-84962, ASTIA AD-270 850, Island Research, Inc., 32 pp.

Harrison, H. T., 1952: Results of 42 tests of Brandau-Kooser method of artificial fog dispersal (B-K Number 2). United Airlines, Inc., Chicago, Ill., 156 pp.

Hicks, J. R., 1965: Experiments on the dissipation of warm fog by helicopter-induced air exchange over Thule AB, Greenland. Special Report No. 87, ASTIA AD-474 070, Cold Regions Research and Eng. Lab., Hanover, N. H., 7 pp.

Hori, T., 1953: Studies on Fog in Relation to Fog-Preventing Forests, (Twenty-five articles). Torme Trading Co., Ltd., Sapporo, Hokkaido, Japan, 399 pp.

Houghton, H. G., and W. H. Radford, 1938: On the local dissipation of natural fog. Papers in Physical Oceanography and Meteorology, Vol. 6, No. 3, 63 pp.

Huschke, R. E. (ed.), 1959: Glossary of Meteorology. Amer. Meteor. Soc., Boston, Mass.

Isono, K., H. Fujita, and M. Komabayasi, 1956: Change in droplets spectrum and water content of a cloud induced by salt water seeding. J. Meteor. Soc. Japan, 34, 1-8.

Jia-Dong, Y., 1962: An experimental study on artificial condensation nuclei. Transl. No. EMM-68-199 by Emmanuel College, Contract No. F19(628)-68-C-0251, AFCRL-68-0629, Air Force Cambridge Research Laboratories, Bedford, Mass., 13 pp.

Jiusto, J. E., 1964: Project fog drops--investigation of warm fog properties and fog modification concepts. (First annual summary report), Cornell Aeronautical Laboratory, Inc., Contract NASR-156, NASA CR-72, National Aeronautics and Space Administration, Washington, D. C., 60 pp.

_______, 1965: Cloud particle sampling. Report No. 6 on NSF G-24850 by Dept. of Meteorology, Pennsylvania State University, University Park, Pa., 21 pp.

_______, 1967: Nucleation factors in the development of clouds. Ph.D. Dissertation, Pennsylvania State Univ., University Park, Pa.

_______, C. L. Hosler, L. G. Davis, and E. J. Mack, 1967: Fog characteristics and modification concepts. Rept. No. 12, NSF GA-7775, Dept. of Meteorology, Pennsylvania State Univ., University Park, Pa., 56 pp.

_______, and R. J. Pilié, 1958: Condensation nuclei experiments with simple apparatus. Weatherwise, 11, 206-208.

_______, R. J. Pilié, and W. C. Kochmond, 1968: Fog modification with giant hygroscopic nuclei. J. Appl. Meteor., 7, 860-869.

Junge, C. E., 1958: Methods of artificial fog dispersal and their evaluation. AFCRC-TN-58-476, ASTIA AD-160 751, AF Surveys in Geophysics No. 105, Air Force Cambridge Research Center, Bedford, Mass., 19 pp.

Kochmond, W. C., and J. E. Jiusto, 1968: Investigation of warm fog properties and fog modification concepts. (Fourth annual report), Rept. RM-1788-P-17 by Cornell Aeronautical Laboratory, Inc., Contract NASR-156, NASA CR-1071, National Aeronautics and Space Administration, Washington, D. C., 56 pp.

_______, and R. J. Pilié, 1969: Project fog drops--investigation of warm fog properties and fog modification concepts. Qtrly Progress Rept., Contract NASR-156, CAL Rept. No. RM-1788-P-22, Cornell Aeronautical Laboratory, Inc., Buffalo, N. Y., 19 pp.

Langmuir, I., 1948: The production of rain by a chain reaction in cumulus clouds at temperatures above freezing, J. Meteor., 5, 175-192.

Lieberman, A., 1960: Warm fog and cloud dissipation. Final rept. ARF-3153-6, Armour Research Foundation, Contract AF19(604)-5910, ASTIA AD-254 489, AFCRL 260, Air Force Cambridge Research Lab., Bedford, Mass., 52 pp.

MacCready, P. B., Jr., and T. R. Mee, 1965: Weather modification for naval applications. Rept. MRI 65-FR-266, Contract N189(188)-58768A, ASTIA AD-478 176, for U. S. Navy Research Facility, Meteorology Research, Inc., Altenda, Calif., 69 pp.

Macdonald, R. J., et al., 1949a: Fog dispersal operations--progress report on 1948 test season. ASTIA ATI-72551, Landing Aids Experiment Station, Arcata, Calif., 17 pp.

_______, 1949b: Tests of a calcium chloride type fog dispersal device for the Army chemical corps., Mem. Rept. No. 49-1. Landing Aids Experiment Station, Arcata, Calif.

Magano, C., K. Kikuchi, T. Nakamura, and T. Kimura, 1963: An experiment on fog disperson by the use of downward air current caused by the fall of water drops. J. Appl. Meteor., 2, 484-493.

Neiburger, M., 1953: Visibility and liquid content in cloud. J. Meteor., 10, 401-404.

"No Fog" Dispersal Equipment, 1947: Bull. Amer. Meteor. Soc., 28, 334.

Odencrantz, F. K., and P. H. Hildebrand, 1969: A technique for direct measurement of the size of small fog droplets. J. Appl. Meteor., 8, 301-303.

Okita, T., 1962: Studies of physical structure of fog. J. Meteor. Soc. Japan, 40, 39-50.

Osmun, W. G., 1969: Airline warm fog dispersal program. Weatherwise, 22, 48-53.

Pauthenier, M., 1950: Electrical coalescence of fog and clouds. Cent. Proc. R. Meteor. Soc., 60-61.

Pilié, R. J., 1966: Project fog drops--investigation of warm fog properties and fog modification concepts. (Second annual summary report), Cornell Aeronautical Laboratory, Inc., Contract NASR-156, NASA CR-368, National Aeronautics and Space Administration, Washington, D. C., 71 pp.

_______, and W. C. Kochmond, 1967: Project fog drops--investigation of warm fog properties and fog modification concepts, Vol. III. (Third annual summary rept.), Cornell Aeronautical Laboratory, Inc., Contract NASR-156, NASA CR-675, National Aeronautics and Space Administration, Washington, D. C., 47 pp.

Plank, V. G., 1954: Fog modification by cold water seeding, AFCRC-TR-54-201, Geophysical Research Papers No. 31, Air Force Cambridge Research Center, Bedford, Mass., 21 pp.

_______, 1964: Comments on 'An experiment on fog dissipation by the use of downward air current by the fall of water drops'. J. Appl. Meteor., 3, 213-214.

Plumlee, H. R., 1964: Effects of electrostatic forces on drop collision and coalescence in air. Rept. CPRL-8-64, Grants AMC-63-G2 and NSF GP-2528, Charged Particle Research Lab., Univ. of Illinois, Urbana, Ill. AD 608382

Rand Corp., 1969: Weather modification and the need for interactive research. Bull. Amer. Meteor. Soc., 50, 216-246.

Schmieschek, U., 1967: Fog dispersal over airport runways by a mechanical method. Transl. rept. RAE-Library Trans-1257, ASTIA AD-827 880, Royal Aircraft Establishment, Farnborough, Eng., 19 pp.

St. Clair, H. W., 1949: Agglomeration of smoke, fog, or dust particles by sonic waves. Ind. Eng. Chem., 41, 2434-2438.

Stewart, K. H., 1960: Recent work on the artificial dispersal of fog. Meteor. Mag., 89, 311-319.

Todd, C. J., and J. W. Nickerson, 1968: CVA fog-dispersal experiment. NAVWEARSCHFAC Tech. Paper No. 28-68, U. S. Navy Weather Research Facility, Norfolk, Va., 20 pp.

Van Straten, F. W., R. E. Ruskin, J. E. Dinger, and H. J. Mastenbrook, 1958: Preliminary experiments using carbon black for cloud modification and formation. NRL Rept. 5235, U. S. Naval Research Laboratory, Washington, D. C., 25 pp.

Wayne, L. G., and G. B. Bell, Jr., 1953: Evaluation of fog dispersal methods. Qtrly. Prog. Report, Contract NOAS 53-005-C to U. S. Navy Bu. Aeronautics, ASTIA AD-20060, Stanford Research Inst., Stanford, Calif., 16 July, 42 pp.

Woodcock, A. H., and A. T. Spencer, 1967: Latent heat released experimentally by adding sodium chloride particles to the atmosphere. J. Appl. Meteor., 6, 95-101.

Workman, E. A. (transl.), 1968: Dissipation of fog. Technical translation FSTC-HT-23-344-68, ASTIA AD-843564, U. S. Army Foreign Science and Technology Center, 6 pp.

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13. ABSTRACT

As a prerequisite to a study of fog dispersal, the literature is surveyed and the various methods of warm fog dispersal are summarized. From an analysis of weather observations during June 1968 - May 1969 at the Naval Auxiliary Landing Field, Monterey, California, it is concluded that the early morning hours of September through November present the highest frequency of fog occurrence and would, therefore, be well suited to fog dispersal field tests. A hand-held, gelatin-coated glass slide method of obtaining fog samples is evaluated in the process of determining the fog droplet distribution in fog and stratus occurring on the Monterey Peninsula. It is found that the distribution is centered about a radius size of 10 μ and in good agreement with current fog models. A series of laboratory experiments using various household detergents as seeding agents are discussed.

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